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PREFACE.

THE first edition of this little book was drawn up expressly for the young officers of the Royal Navy; and I then stated that my object was to help them, in what I knew by experience they considered the most troublesome part of their studies. In my preface I wrote as follows:—"The author would give this help by teaching them to regard scientific and technical terms not as necessary evils, but as very useful servants, by the rational use of which a definiteness of conception may be acquired not otherwise attainable. It is also his hope in some small measure to aid in banishing a prevailing looseness of phraseology, and in bringing about a consistency of usage in nautical terms." In this object I was greatly assisted by my college friend, the late Mr. Hugh Godfray, who expressed his opinion thus:—"Nothing stands more in the way of a student's real progress than loose notions in the early stages of the subject he is attacking, although such loose notions are often the natural result of loose wording on the part of the author."

This second and enlarged edition is intended for more extended circulation, and it is hoped that it will be found useful not only to the officers of the Royal Navy, but to those aspiring to or actually in command of vessels in our Mercantile Marine, and to those enlightened and enterprising gentlemen whose love for the sea has covered it with Yacht Squadrons. To all I would repeat the above counsel; and further, I would add some words of Admiral Shadwell, which embody the true method of studying Navigation. He writes :—"I am glad to see that you deal liberally in diagrams, and give the mathematical formulæ, avoiding long and tedious verbal precepts. I am fully persuaded that our officers will never be properly instructed in Nautical Astronomy until they make up their minds to discard verbal rules, and to grapple with the formulæ themselves on which they depend." Dr. Woolley remarks :—"Further, I believe it is most important that the memory, always very liable to fail, should have very little to do. A person whose business it is to apply rules of navigation should, at all times, not only work from formulæ, but be able for himself to reproduce these formulæ, or equivalents, from first principles, and in very short time."

Under each term, besides what is necessary to explain it fully in its different bearings, will be found an analysis of what is to be learned on the subject by systematic reading. In the arrangement of the articles the strictly alphabetical order has sometimes been departed from, as regards the subdivisions of a general head, and what appears in each case to be the natural order has been adopted.

In this task of classifying and arranging, I was led to feel the want of appropriate terms for the two great branches of the science of Navigation. This word Navigation has been dethroned from its rightful position, though no usurper has taken its place. It has simply been degraded by modern writers to fill a very subordinate *rôle*. I have attempted to restore the term to the meaning it had a century ago, when the most scientific book on the subject in the English language was written, and I have uniformly, therefore, used "Navigation" as the generic word, and the two great subdivisions I have named geo-navigation and celo-navigation. Geography, meteorology, astronomy should all be equally regarded as ancillary sciences. Arithmetic, geometry, and trigonometry, serving as the essential basis of the whole, always formed the introductory chapters of the old treatises on Navigation.

There is another word, I introduced in my first edition, which, strange to say, was not previously found in any book on Navigation, viz. "co-ordinates". This appears to have frightened some, who want no new terms to describe what they have themselves thoroughly mastered without them. But its very general adoption in all schools for young officers, and in many books since published, is a complete vindication of the assistance this one term has given to scientific study based on systematic arrangement.

I have retained the derivations of the terms in the present edition. Those who consider this superfluous can pass them over; but I look upon them as valuable for several reasons: they sometimes explain a word without the necessity of any long description; they make it easy to remember the term; and they frequently embody its history in a manner both interesting and instructive.

The last point brings me to state why some obsolete words have been inserted, such as "astrolabe," "cross-staff". A sufficient reason might be found in these words sometimes occurring in an officer's reading, and ordinary dictionaries not affording sufficient help as to their meaning. But there is another value attached to them. A sailor's life may deprive him of the refined means of navigation which modern advancement has placed at his disposal, and he may find himself thrown back upon his own resources, perhaps to navigate a boat without even compass or sextant. In such circumstances he would find it invaluable to know something of the rude contrivances of early navigators.

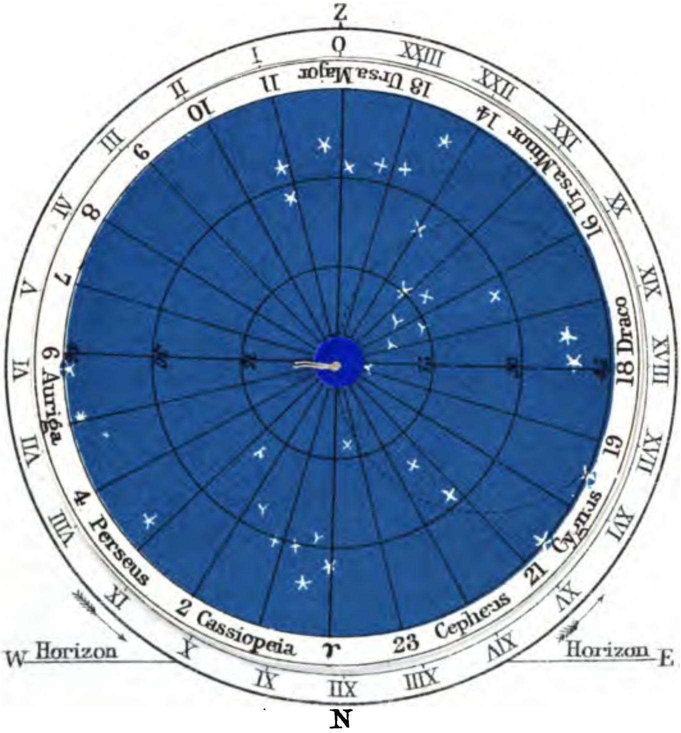
Some topics are treated of at greater length than might appear necessary, and to engross more than their share of room; but this has been done advisedly. There are some points on which very loose ideas are common and some space is necessary as, in such cases, explanation, to be of any use, must be full. The terms "celestial concave" and "horizon" are illustrations; and special attention has to be paid to words which have several different meanings, such as, for example, "distance". Again, very contradictory information is given by different authorities on some points, as, for instance, the meaning and length of the "mile". Once more, information stowed away in old magazines and pamphlets, and not generally found in the usual text-books, is given at length; and this must be the excuse for the full treatment, for example, of "Chronometer Diagrams". Finally, a new method which, up to the present moment, can only be read in the *brochure* of its author, is given at large: I refer to Airy's new method of clearing the "lunar distance". One topic of vital importance has been enlarged upon for many reasons, viz. "Magnetism and Compass Deviation". In dealing with this the chief guide has been found in the memory of Airy's lectures at South Kensington and his syllabus. For important and the latest information on this subject I am greatly indebted to Staff-Commander Ettrick W. Creak, R.N.

I have to return my best thanks to Captain Sir Frederick J. O. Evans, the Hydrographer, for his assistance, and to acknowledge the valuable suggestions I have received from Dr. J. Woolley, the Rev. F. Davies, R.N., Mr. H. B. Goodwin, R.N., Staff-Commander T. A. Hull, R.N., and Mr. A. Escott. To Mr. Escott and Mr. G. C. Pulsford I am grateful for the trouble they have taken to ensure the accuracy of the work.

In conclusion, I beg to introduce my book as a confidential and silent friend, that will remove your difficulties without exposing your ignorance.

J. B. HARBORD.

NORTH CIRCUMPOLAR STAR DISC.



Star Magnitudes.

✱ 1st ★ 2nd, + 3rd ⅄ 4th &c.

Circumpolar Star Discs.

These represent approximately the positions of the stars within 45° from the poles at any hour of a given day, in any longitude. The observer is supposed to be in latitude 45°.

The outer fixed rim of the disc represents the hours of the day; the inner movable rim is graduated for right ascensions.

Face towards the elevated pole; and hold the proper disc over the head, so as to view it as you would look at the heavens.

To set the Disc.

Take out of the "Nautical Almanac" the Sidereal Time, which is the same as the right ascension of the mean sun at mean noon at Greenwich. This may be obtained with sufficient accuracy, without referring to the "Nautical Almanac", from the following table, which gives the astronomical days when the sidereal time is so many complete hours:—

1 hour,	6 April	7 hours,	6 July	13 hours	5 October	19 hours	5 January
2 „	21 „	8 „	21 „	14 „	21 „	20 „	20 „
3 „	6 May	9 „	6 August	15 „	5 Nov.	21 „	4 Feb.
4 „	21 „	10 „	21 „	16 „	20 „	22 „	19 „
5 „	6 June	11 „	5 Sept.	17 „	5 Dec.	23 „	6 March
6 „	21 „	12 „	20 „	18 „	21 „	24 „	22 „

First—consider ZN or ZS to represent the meridian of Greenwich. Place adjacent to Z, by revolving the disc, the number indicating the sidereal time just found. Then the disc will represent the position of the heavens, at Greenwich mean noon, to an observer on the meridian of Greenwich, in latitude 45°.

Secondly—Add the time at place to the sidereal time and revolve the disc till the number, so obtained, on the inner rim comes adjacent to Z. The disc will now represent the required position of the heavens at the time, ZN or ZS being the meridian of the place.

By the aid of these discs may also be found the time when any star, within the region, will pass the meridian at both its transits.

Equinoctial Star Chart.

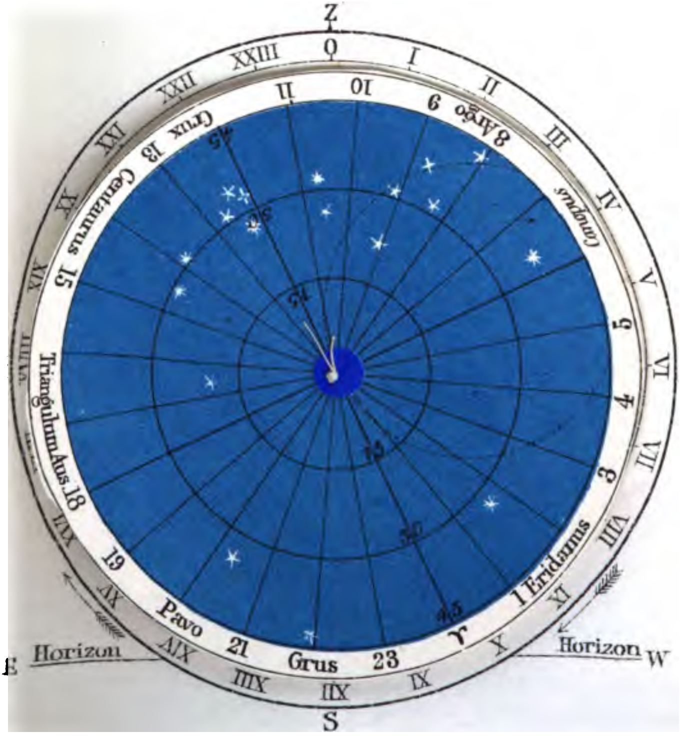
At article **Lunar Distances** will be found a chart which, with the two circumpolar discs, completes the view of the heavens. It embraces from the equinoctial to 45° N., and to 45° S. declination, thus comprehending a zone of 90°.

In using this chart, it should be held above the head so that the central horizontal line corresponds with the equinoctial.

At p. 228, in the explanation of this chart, should be added to the four fixed stars given as lunar-distance bodies the following, which have a proper motion:—

Sun.	W.	120° 53′ 18″
Mars	W.	97° 39′ 24″
Venus	W.	74° 59′ 13″

SOUTH CIRCUMPOLAR STAR DISC.

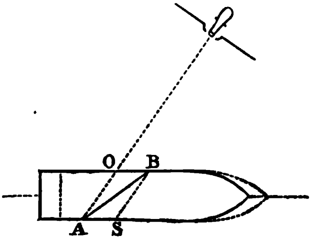


Star Magnitudes.

✱ 1st ⋆ 2nd + 3rd ⅄ 4th, &c.

GLOSSARY OF NAVIGATION.

Aberration (L. *aberratio*, "a going out of the way").—The disturbance in the apparent direction of an object caused by the combination of its motion with that of the spectator. The following illustration is given by Airy:—If a shot, fired from a battery, penetrate the side of a ship in motion and pass out on the other side, it will do so somewhat abaft, and thus it will appear to have been fired from more ahead than it was in reality. Let OA and AS represent, in direction and rate, the motions respectively of the object and spectator. Then, in consequence of the motion AS of the spectator, that of the object will appear to him to be in the direction BA instead of OA; and the angle BAO is the aberration. The apparent change in the rate $BA \sim OA$ might be properly called the acceleration. The quantities involved are connected by the relations:—



$$(1)\ \frac{AS}{OA} = \frac{\sin BAO}{\sin BAS}; \qquad (2)\ \frac{AS}{BA} = \frac{\sin BAO}{\sin OAS}$$

Aberration in Astronomy.—The principle explained above was applied by Astronomer Royal Bradley, in 1728, to account for an apparent motion of the fixed stars which could not be assigned to any known cause. He ascribed it to the progressive motion of light combined with the earth's annual motion in its orbit. Light is propagated with a velocity of 192,000 miles per second, the earth moving in its orbit during that interval about 19 miles; and the ratio 1 to 10,000 produces very appreciable results. In consequence of the combination of these two things, the light by which a celestial object is seen has its direction apparently changed. This is spoken of as the *Aberration of Light*, and it causes the apparent positions of objects on the celestial concave to be disturbed. The general result is that all the stars seem to be displaced from their mean positions, towards that point of the heavens to which the direction of the earth's motion tends at any moment; and thus each star will apparently describe, during the year, a small ellipse in the heavens, having for its centre the point in which it would be seen if the earth were at rest. The *correction* to be applied to the apparent place of a celestial body, consequent upon the aberration of light, is technically called the *Aberration*. The sine of the aberration is proportional to the sine of the angle made by the earth's motion in space with the visual ray, which angle has been called "The Earth's way." The aberration being small, the circular measure may be written for the sine, and we have:—

$$\begin{aligned}\text{Aberration} &= \frac{\text{velocity of Earth}}{\text{velocity of Light}} \cdot \sin(\text{Earth's way}).\\ &= k \,.\, \sin(\text{Earth's way}),\end{aligned}$$

where k is the *Coefficient of Aberration* and is constant for all bodies seen on the celestial concave. In the case of the moon and planets, which have a proper motion of their own, the light by which the body is seen comes from a point in space which the body no longer occupies when the rays reach the observer on the earth. The result is generally combined with aberration properly so called, but is more strictly distinguished as the *Equation of Light*, being the allowance to be made for the time occupied by the light in traversing a variable space. The value of k has been determined from observations made at Greenwich Observatory to be $20''\cdot307$. The *Correction for Aberration* is important in reducing the elements, given in the Nautical Almanac, upon which the navigator depends; but its amount is too small to be taken directly into account, in correcting the observations he himself makes at sea.

Aberration in Meteorology.—We propose that the term "aberration" be adopted in Meteorology, in a sense analogous to that which it so conveniently bears in Astronomy. The commonest illustration, used to explain the aberration of light, is derived from the phenomenon of drops of rain, which, falling vertically on a person at rest, appear to meet him and come down quicker if he runs forward. But the best vindication of this use of the term is found in the history of the discovery of astronomical aberration. Dr. Bradley observed a motion of the fixed stars, which he could not account for by any recognized causes. Annual parallax, the nutation of the earth's axis, refraction, an alteration in the plumb-line by which the observing instrument was rectified, were all inadequate. "At last, when he despaired of being able to account for the phenomena which he had observed, a satisfactory explanation of it occurred to him all at once, when he was not in search of it. He accompanied a pleasure party in a sail upon the river Thames. The boat, in which they were, was provided with a mast, which had a vane at the top of it. It blew a moderate wind, and the party sailed up and down the river for a considerable time. Dr. Bradley remarked, that every time the boat put about, the vane at the top of the boat's mast shifted a little, as if there had been a slight change in the direction of the wind. He observed this three or four times, without speaking; at last he mentioned it to the sailors, and expressed his surprise that the wind should shift so regularly every time they put about. The sailors told him that the wind had not shifted, but that the apparent change was owing to the change in the direction of the boat, and assured him that the same thing invariably happened in all cases. This accidental observation led him to conclude, that the phenomenon, which had puzzled him so much, was owing to the combined motion of light and of the earth. Since light does not move instantaneously from one place to another, it is clear that a spectator, standing on the earth's surface, will not see a star by means of the same ray of light, if the earth be moving, that he would do if the earth were standing still. . . . Hence the star will not appear in its true place, but will be seen in the diagonal of the parallelogram, whose two sides are the velocity of light and its direction from the star, and the velocity and direction of the earth in its orbit." (*History of the Royal Society*, Thomas Thomson, 1812, p. 346).—See **Wind, Aberration of.**

Aberration in Optics.—There is another and a different technical use of the term aberration, also important to those whose calling necessitates the use of optical instruments. In optics, it signifies the deviation of the rays of light from the true focus of a curved lens or speculum, the result being a somewhat confused image of the object.

Acceleration (L. *acceleratio*, "a hastening").—An increase in the rate of motion, such motion in Astronomy being that of revolution. Acceleration is the opposite of *Retardation*. The rate may be viewed with reference to (I.) the motion of the one body under consideration, or (II.) to the motion of this body relatively to that of others.

(I.) When one body only is regarded, the acceleration and retardation of its motion are referred to its mean rate. Thus (1) the Planets when moving from aphelion of their orbits have their motion accelerated, and when moving from the perihelion of their orbits have it retarded; the rate thus oscillating about the mean: this is spoken of as the *Acceleration and Retardation of the Planets.* But (2) the mean motion of a revolution or period may itself go through a cycle of change, this acceleration and retardation being completed in a long age (*seculum* "a lifetime"). Such is the present increase and future decrease of the mean angular velocity of the moon about the earth, a change spoken of as the *Secular Acceleration and Retardation of the Moon.*

(II.) The daily apparent revolution of the stars may be referred to that of the sun. In consequence of the sun travelling in the ecliptic from W. to E., while the apparent rotation of the heavens is from E. to W., the stars appear to have a greater diurnal motion than the sun. This is spoken of as the *Acceleration of the Fixed Stars.* The term retardation would be here applied to the other body, and we might speak of the *Retardation of the Sun* with reference to the stars.

Acceleration of Sidereal on Mean Solar Time.—The change of the mean sun's right ascension in a mean solar day, in consequence of which, in the interval of his coming successively to the meridian, the first point of Aries appears to have hastened forward in its diurnal revolution; hence the name. To explain this, let MPV (fig. 1) be the sidereal time, when the mean sun is on the meridian of Greenwich on a particular day. When the mean sun comes again to the meridian after a mean solar day, he will have moved in right ascension to the east through MM′ say (fig. 2). The sidereal time corresponding to this second mean noon will be M′PV instead of MPV; the first point of Aries thus appearing to have hastened forward in its diurnal revolution, and the sidereal time to be "accelerated" with reference to mean solar time. The angle M′PM, which is the acceleration, is a portion of sidereal time. The amount of acceleration, for any given interval of mean solar time, will enable us to deduce the side-

Fig. 1.

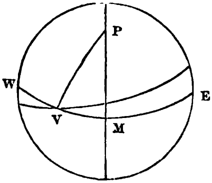
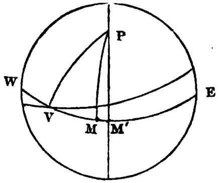


Fig. 2.



real time. In the Nautical Almanac, pp. 478, 479, is given a "Table for Converting Intervals of Mean Solar Time into Equivalent Intervals of Sidereal Time." Similar tables are also given in treatises on navigation. —See **Retardation of Mean Solar on Sidereal Time.**

Achernar.—The Arabic name for the bright star *a Eridani.*—See **Eridanus.**

Adjustments of Instruments.—All nautical instruments are liable to get out of order; their several parts not retaining their relative positions, owing to unequal expansion, violence, or like causes. To guard against resulting errors, before observing, there are *methods of testing* whether the instrument is in order in the several points subject to be affected; and the instrument is provided with *means of adjustment*, chiefly in the form of screws or sliding weights, by which it may be restored to its correct state. Adjusting screws and weights ought not to be touched more than is absolutely necessary, and then with great care. When two such screws work oppositely to each other, one must not be tightened without the other being previously loosened. Sometimes, instead of making the adjustment, the error may be acknowledged and allowed for in observing. The term "adjustments" is often loosely applied both to all sources of incorrectness, and the means of obviating their effects, in using instruments. These are, however, properly of three distinct kinds: (1) *Imperfections* in the instrument, which should cause its rejection; (2) *Adjustments* for parts of the instrument liable to temporary derangement, but which can be restored to order by the machinery attached; (3) *Errors* of the instrument, which are acknowledged, determined by experiment, and allowed for. It would be well if the term "adjustments" were always strictly limited to the second of these.

Adjustments of the Azimuth Compass.—The adjustments of the azimuth compass are commonly said to be the following:—(1) The "magnetic axis" should coincide with the longitudinal line of the needle; (2) The pivot should be in the centre of the graduated circumference of the card; (3) The "line of sight" should pass directly over the pivot; (4) The eye-vane and object-vane should each be vertical; and (5) The needle, with card, should work upon its pivot horizontally. But of these (1) is properly treated as an *error* of the instrument; (2), (3), and (4) as *imperfections;* (5) only strictly coming under the head of *adjustments.*—See **Compass, Imperfections, Adjustments, Errors.**

Adjustments of the Sextant.—The adjustments of the sextant are:—(1) The "index-glass" should be perpendicular to the plane of the arc; (2) The "horizon-glass" should be perpendicular to the plane of the arc; (3) The "line of collimation" of the telescope should be parallel to the plane of the arc; and (4) For distant objects, when the zero of the vernier coincides with the zero of the arc, the horizon-glass and the index-glass should be parallel. The last is generally, in practice, treated as an *error.*—See **Sextant, Imperfections, Adjustments, Errors.**

Age of the Moon.—The "age of the moon" is reckoned from new moon, through a *lunation* or *lunar month,* the mean length of which is about 29½ days. It is given in the Nautical Almanac, p. iv., for every mean noon at Greenwich.

Age of the Tide.—The interval between the transit of the moon, at which a tide originates, and the appearance of the tide itself. Called also *Retard of the Tide.*—See under **Tide.**

Alamak.—The Arabic name for the bright star γ *Andromedæ.*—See **Andromeda.**

Aldebāran (Arabic, "The Bull's Eye").—The large and bright star, of the first magnitude, situated in the eye of the constellation Taurus ("The

Bull"), in modern catalogues known as *α Tauri*, but still generally called by its Arabic name, Aldebaran. It is a very important star to the navigator, being one of those whose "lunar distances" are calculated and tabulated in the Nautical Almanac. It is also easily found. The two remarkable groups, the Pleiades and Hyades, at once point out Taurus, and Aldebaran is among the small stars of the latter, conspicuous by its ruddy colour. It is at about the same distance from Orion's Belt on the one side that Sirius is on the other, and a line drawn from the Pole Star a little to the westward of Capella will pass through no great star till it comes to Aldebaran. 1882, R.A. 4^h 29^m, Dec. + 16° 16′.—See **Taurus.**

Algebraic Signs.—The algebraic signs can be conveniently applied to qualify astronomical and geographical elements which are reckoned in opposite directions from their origin. This enables us to connect them, in formulæ, with other quantities, without making two cases of the problem. In the Table "Mean Places of Stars," given in the Nautical Almanac, pp. 290–293, north declinations are marked +, and south declinations are marked −.

Algenib.—The Arabic name for the bright star *γ Pegasi.*—See **Pegasus.**

Algol.—The Arabic name for the bright star *β Persĕi;* also known as *β Medusæ.* It is remarkable as being a "variable" star, changing from the second or third magnitude to the fifth in the period of 2^d 20^h 50^m.—See **Perseus.**

Alioth.—The Arabic name for the bright star *Capella, α Aurigæ.*—See **Auriga.**

Almacantars, Almucantars, or **Almicanthers.**—The Arabic term for *Parallels of Altitude.* These parallels were conceived to be drawn through every degree of the meridian. Obsolete.

Almanac.—The Arabic name for *The Diary;* its use, especially as applied to the annual register of astronomical phenomena calculated beforehand, indicates, with numerous similar words, the channel through which our navigators have received much of the science on which their art depends.—See **Nautical Almanac** ; **Connaissance des Temps.**

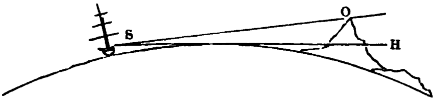
Alphard.—The Arabic name for the bright star *α Hydræ.*—See **Hydra.**

Alpheratz.—The Arabic name for the star *α Andromedæ.*—See **Andromeda.**

Altair.—The Arabic name for the bright star *α Aquilæ.*—See **Aquila.**

Altitude of a Celestial Body (L. *altitudo,* "height").—The angular distance of the body from the horizon. It is measured by the arc of a circle of azimuth (which is hence generally called a "circle of altitude") passing through the place of the body, intercepted between the body and the horizon, or by the corresponding angle at the centre of the sphere. The term altitude may be considered to apply not only to *elevation above* the horizon, but also to *depression below* it; and in that case it is reckoned from the horizon, from 0 to 90°, to the zenith positive (+), and to the nadir negative (−). The complement of the altitude is the zenith distance. Azimuth and altitude are the horizon co-ordinates for describing points of the celestial concave relatively to the position of an observer on the earth's surface.—See **Azimuth and Altitude.**

Altitude of a Terrestrial Object above the Sea Horizon.—The angle included between two lines drawn from the eye of the observer, the one to the horizon, the other to the object. Thus in the example illustrated by the figure, HSO is the altitude of the mountain above the sea horizon.



Altitude—distinguished as **Observed, Apparent,** and **True.**—The altitudes of heavenly bodies are observed, from the deck of a ship at sea, with the sextant for the different problems of celo-navigation. Such an altitude is called the "*Observed Altitude.*" There are certain instrumental and circumstantial sources of error by which this is affected; (*a*) The sextant (supposed otherwise to be in adjustment) may have an index error; (*b*) The eye of the observer being elevated above the surface of the sea, the horizon will appear to be depressed, and the consequent altitude in reality too great; and (*c*) One of the limbs of the body may be observed instead of its centre. When the corrections for these errors and method of observing are applied—the "index correction," "correction for dip," and "semidiameter"—the observed is reduced to the "*Apparent Altitude.*" But again, for the sake of comparison and computation, all observations must be transformed into what they would have been had the bodies been viewed through a uniform medium, and from one common centre—the centre of the earth. The altitude, supposed to be so taken, is called the "*True Altitude.*" It may be deduced from the apparent altitude by applying (*a*′) the "correction for refraction" and (*b*′) the "correction for parallax," which two corrections, however, are sometimes given in tables combined under the name "Correction in Altitude." When a body is viewed through the atmosphere, refraction will cause the apparent to be greater than the true altitude; hence the correction for refraction is subtractive in finding the true from the apparent altitude. The position of the observer on the surface, especially for near bodies, will cause the apparent to be less than the true altitude; hence the correction for parallax is additive in finding the true from the apparent altitude.

Altitude, Meridian.—The altitude of a celestial body when on the meridian. In the case of a circumpolar star, whose whole diurnal circle is completed above the horizon, the body comes to the meridian twice, when its altitudes are spoken of respectively as "the Meridian Altitude below the Pole," and "the Meridian Altitude above the Pole;" the former is the lowest altitude the body has in its revolution, the latter the highest. The meridian altitude is easily observed at sea with a sextant, and furnishes the simplest and most satisfactory method of determining the latitude, the declination of the body only being required in addition.—See **Latitude, how determined.**

Altitudes, Meridian, Circummeridian, and **Exmeridian.**—An altitude of a body when it is on the meridian is called the *Meridian Altitude;* when the body is near the meridian, and altitudes are observed with a view of solving problems by first finding from these the meridian altitude, such altitudes are conveniently distinguished as *Circummeridian Altitudes;* when altitudes of a body off the meridian are observed with a view of solving problems independently of the meridian altitude, such observed altitudes we distinguish as *Exmeridian Altitudes.*

Altitude, a Double.—Two altitudes taken for the solution of the same problem. Raper suggests the more correct term, "*Combined Altitudes.*" The ordinary problems, for which the method furnishes the data, are finding the latitude and rating a chronometer. These altitudes may be of the same body, taken at different times, either on the same side or on opposite sides of the meridian; or, of different bodies similarly situated observed at the same time; or, lastly, of different bodies similarly situated observed at different times.—See **Latitude, how determined; Chronometer, Error of.**

Altitudes, Equal.—Combined altitudes of the sun, when at the same altitude in the forenoon and afternoon; these observations furnish a valuable means of rating the chronometer.—See **Chronometer, Error of.**

Altitudes, Simultaneous.—Combined altitudes of different bodies taken at the same time.

Altitude, Circles of.—Great circles of the celestial concave perpendicular to the horizon, and so called because "altitudes" are measured on them. They all pass through the poles of the horizon, of which the superior is the "vertex" of the visible heavens, and hence they are also called "*Vertical Circles*,"' or simply "*Verticals*." In a polar system of horizon co-ordinates they are termed "*Circles of Azimuth*," as marking out all points that have the same "azimuth."—See **Co-ordinates for the Surface of a Sphere.**

Altitude, Parallels of.—Small circles of the celestial concave parallel to the horizon. They mark all the points of the heavens which have the same altitude. The Arabic term for this system was "*Almucantars*." Compare "Parallels of Declination," "Parallels of Latitude."—See **Co-ordinates for the Surface of a Sphere.**

Altitude, Circles or Parallels of Equal.—Circles on the earth's surface, from every point of each of which a given heavenly body is observed to have the same altitude at any given time. The circle of equal altitude is a great circle of the sphere when the body is in the horizon, or its altitude 0; the circle is reduced to a point when the body is in the zenith, or its altitude 90°; and between these two limits the parallels are small circles whose radii correspond to the complements of the altitudes. A small arc of a circle of equal altitude, when projected on a Mercator's chart, will be approximately a straight line, especially if the altitude of the body be low. Such a line is called "*A Line of Equal Altitude*." The determination of one, or two such lines intersecting each other, forms the basis of what is called "Sumner's Method" of finding a ship's position at sea.—See **Sumner's Method.**

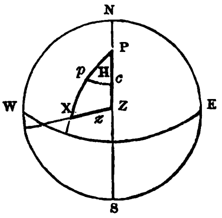
Altitude, Correction in.—The total correction to be applied to the apparent altitude to deduce the true altitude. In the case of the stars, it is due solely to refraction, but for appreciably near bodies, to the combined effects of refraction and parallax. Separate tables of the "Correction in Altitude" are given in works on navigation for the stars, the sun, and the moon.

Altitudes, Equation of Equal.—In observing equal altitudes of the sun, its declination changes slightly in the interval between the forenoon and the afternoon observation, and therefore the hour-angles corresponding to the two altitudes are not exactly equal. Hence half the interval added to the time of the first observation requires a correction, in order to give the time shown by chronometer when the sun is on the meridian. This correction is called "The Equation of Equal Altitudes." It is given in tables.

Altitude, Reduction of, to another Place of Observation.—See **Run.**

Altitude, Motion in.—An instrument is said to move "in altitude" when it is turned on a horizontal axis; in contradistinction, it is said to move "in azimuth" when it is turned on a vertical axis. An *azimuth and altitude instrument* admits of both motions.

Altitude, how found by Calculation.—Given the latitude of the place (l), the declination of the celestial body (δ), and the hour-angle (H), to find the altitude of the body (a). Project on the horizon. Z is the zenith, P the elevated pole, and X the body. Let $c = 90 - l, p = 90 \pm \delta, z = 90 - a$. Then in the triangle PZX, $\cos z = \cos c \,.\, \cos p + \sin c \,.\, \sin p \,.\, \cos \mathrm{H}$.



This, reduced for logarithmic computation, gives the following three methods of solving the problem, according to the tables in use:—

(I.)

$$\operatorname{Sin} \frac{z}{2} = \frac{\operatorname{Sin} \frac{\mathrm{H}}{2} \cdot \sqrt{\sin c \,.\, \sin p}}{\sin \theta}$$

Where θ is obtained from the formula

$$\operatorname{Tan} \theta = \frac{\sin \frac{\mathrm{H}}{2} \cdot \sqrt{\sin c \,.\, \sin p}}{\sin \frac{1}{2} (c \sim p)}$$

(II.) $\operatorname{Vers} z = \operatorname{vers} (c \sim p) + \operatorname{vers} \theta$

Where vers θ is obtained from the formula

$$\operatorname{Vers} \theta = 2 \sin c \,.\, \sin p \,.\, \sin^2 \frac{\mathrm{H}}{2}$$

(III.) $\text{Vers } z = \text{vers } (c \sim p) + \text{vers } \theta$

Where vers θ is obtained from the formula

$$\text{Vers } \theta = 2 \sin c \sin p \,.\, \text{hav H}.$$

In the above formulæ $(l \sim \delta)$ may be used instead of $(c \sim p)$.

Method (III.) is the shortest, and is more fully expressed as follows:—
Log. tab. vers. $\theta = \text{L.cos } l + \text{L.cos } \delta + \text{L.hav. H} - 30 + 6{\cdot}301030$.

To the natural number corresponding to this log., add tab. vers $(l \sim \delta)$, and it will give the tab. vers z, from which a may be found.

An application of this problem may be seen in one of the methods of working a lunar.

A.M.—The initials of "*Ante Meridiem*," "Before Noon," opposed to P.M., "*Post Meridiem*," "After Noon."

Amplitude of a Heavenly Body (L. *amplitudo*, "extent").—The distance from the "east point" at which the body rises, or the distance from the "west point" at which it sets; these distances being arcs of the horizon measured northward or southward. The amplitude is sometimes called the *Rising* or *Setting Azimuth*, and is then reckoned from the north or south point, according as the south or north pole is elevated. It has been objected to the continuance of this term, Amplitude, that we generally in fact observe the bearing of the body with the azimuth compass from the N. or S., and then convert this to its bearing from E. or W. But it is, on the other hand, advantageous to retain a term so expressive and marking a particular case. It is as natural to speak of the amplitude—referring the body to the E. or W. point—as it is to speak of a sail two or three points abaft or before the beam.

Amplitude, True.—The bearing of a celestial body at rising or setting (*i.e.*, when its centre is on the *rational* horizon) from the *true* east or west point; found by calculation from the latitude of the place and the declination of the body, or taken by inspection from a table of which these quantities are the arguments. It is in general simply called "*the Amplitude*," but it is sometimes qualified as the *True* Amplitude, to distinguish it from the *Compass* and *Magnetic* Amplitude.

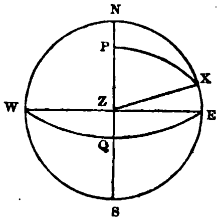
Amplitude, Compass.—The bearing of a celestial body at its rising or setting from the *compass* east or west point; found by direct observation with an instrument carrying a magnetic needle, corrections being then made for dip, refraction, and parallax. The difference between the true and compass amplitude gives the correction (variation and deviation combined) of the compass.

Amplitude, Magnetic.—A term sometimes used for the bearing of a celestial body at rising or setting from the compass east or west points; found by direct observation with an instrument on shore when not affected by deviation. It is distinguished from the *True* Amplitude, or *Amplitude* properly so called, and from the *Compass* Amplitude.

Amplitude, Magnetic—distinguished as **Observed** and **Corrected.**—The "*Observed*" Magnetic Amplitude of a celestial body is its bearing from the compass east or west point when it appears in the sea-horizon of an observer standing on the deck of the ship. The "*Corrected*" Magnetic Amplitude is the bearing of the body from the compass east or west point when on the rational horizon, as it would appear to a spectator at the centre of the sphere through a uniform medium. The diurnal circles of the celestial bodies being, except at the equator, inclined to the horizon, and more and more so the higher the latitude, any cause which affects the time of rising will affect the apparent amplitude, and in a degree becoming greater as the latitude increases. These causes are the following:—(1) The elevation of the observer depresses the sea-horizon, while it does not affect the place of the celestial body—hence, by reason of the *dip*, the body appears to rise before it is truly on the sensible horizon; (2) The great *refraction* at the horizon causes the body to appear to rise considerably before it comes to the sensible horizon; (3) When a body is in the sensible horizon, to an eye at the centre of the sphere it has already passed the rational horizon. This, being the effect of *parallax*, is only of importance in the case of the moon. These corrections will be found in the tables given in the ordinary treatises on navigation.

Amplitude, Bearing and Time.—By the "Bearing Amplitude of the Sun" is meant the arc of the horizon intercepted between the east point and the point where the sun rises, or between the west point and the point where it sets. By the "Time Amplitude of the Sun" is meant the time he rises before or after 6 A.M., or sets after or before 6 P.M. When the latitude and declination are of like names, the sun rises so much before 6 A.M. and sets so much after 6 P.M.; when they are of different names, the sun rises so much after 6 A.M., and sets so much before 6 P.M.

Amplitude, Observation of.—The usual instructions, for taking amplitudes, are laid down with the view that the body shall be observed at the moment when its centre is really in the rational horizon. Thus the bearing of the sun is directed to be taken when its lower limb appears half-way between the horizon and its centre; the bearing of a star is to be taken at an altitude of 34′: the amplitude of the moon cannot be thus directly observed with accuracy, especially in high latitudes, by reason of her great depression by parallax, but may be found approximately by observing her bearing when her upper limb is in the horizon. In all cases, however, the better plan is to obtain by observation the bearing when the centre of the body appears on the horizon, and apply the necessary corrections (for dip, refraction, and parallax) taken from a table. For the sun, when rising, observe the bearing of the upper limb as it appears on the horizon, and continue to take bearings of the vertex until the lower limb appears. Read off each bearing. At sunset, when the lower limb touches the horizon, proceed in like manner until the upper limb disappears. The mean of the readings, reckoning from the east or west point, is the observed amplitude of the centre. When practicable, the moon may be observed in the same way. In the case of the sun and stars, a table (with latitude, and declination for arguments) gives the necessary correction for refraction, to which the requisite dip is added. The same table applied in the *contrary* way gives the correction for the moon, which is the excess of the effect of parallax over the combined effects of refraction and dip. The amplitude of a star should be observed at *setting*, to admit of the body being easily identified.



Amplitude, how found by Calculation.—The figure is a projection on the horizon. NS is the meridian, EQW the equator, Z the zenith, P the elevated pole, and X the body in the horizon. Then PZX is a quadrantal triangle ($ZX = 90°$), in which, having given PZ the colatitude ($c = 90 - l$), PX the polar distance ($p = 90 \pm \delta$), we can determine the angle PZX, which is the complement of EZX the amplitude (a).

$$\text{Cos PX} = \sin \text{PZ} \,.\, \cos \text{PZX}$$
$$\sin a = \sin \delta \,.\, \sec l$$
$$\therefore \text{L.sin } a = \text{L.sin } \delta + \text{L.sec } l - 10.$$

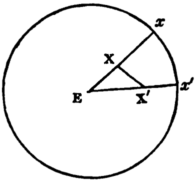
The amplitude can be taken out by inspection of a table constructed for the purpose, and given in most works on navigation, the arguments being the declination and latitude. The principal application of this problem is in finding the correction (variation and deviation combined) of the compass.—See **Compass Corrections.**

Andromeda.—A constellation between Pegasus and Perseus, and to the south of Cassiopeia and Cepheus. These groups were named by the Greeks after persons in their mythology. Andromeda was the daughter of Cepheus and Cassiopeia, who, being bound to a rock, exposed to a sea-monster, was delivered by Perseus. The four stars of Pegasus, forming a remarkable square, can always be recognized after being once pointed out: one of these stars (the most northerly) is common to Pegasus and Andromeda, and called δ *Pegasi* or α *Andromedæ.* The three principal stars of Andromeda form a line joining Pegasus to Perseus, α *Andromedæ* (called *Alpheratz*), mag. 2; 1882, R.A. $0^h\ 2^m$, Dec. + 28° 26′. β *Andromedæ* (called *Mirach*), mag. 2.3; R.A. $1^h\ 3^m$, Dec. + 34° 59′. γ *Andromedæ* (called *Alamak*), mag. 2.3.

Aneroid Barometer (Gk. α, "without;" νηρὸς, "fluid").—A barometer into the construction of which mercury or other fluid does not enter. Other derivations of the word have been given; thus it is said that M. Vidi, the inventor, intended to call the instrument an *Aneroid Baroscope*, as by it the pressure of the atmosphere is "perceived," in a manner similar to that by which changes in elasticity of the atmosphere affect the body of a man (ἀνὴρ, "a man").—See **Barometer.**

"Angle of the Vertical."—See **Latitude, Reduction of.**

Angular Distance.—The angular distance of two remote bodies is their apparent distance, as measured by the angle they subtend at the eye of the observer. This is an important element in celo-navigation, for all heavenly bodies appear on the surface of the celestial concave, and it is by their observed angular distances that their relative positions furnish data in the problems of navigation. Thus, let E be the centre of the earth, X and X′ two heavenly bodies at an absolute distance from each other XX′. They appear, as seen from E, to be projected at x and x' on the celestial concave. The angle XEX′, or the arc xx', is called their angular distance.



Antarctic Circle (Gk. ἀντὶ, "opposite to;" ἄρκτος, "The Bear").—The "*South Polar Circle,*" or parallel of latitude of about 66° 32′ S. It encircles the south pole at the same distance from it as the tropical circles are from the equator (about 23° 28′), and it includes within it the south frigid zone, which it separates from the south temperate zone. It is called the "Antarctic" circle, as being on the *opposite* (ἀντὶ) side of the globe to the "Arctic" circle.—See **Arctic Circle.**

Antares.—The Arabic name for the bright star *α Scorpii.*—See **Scorpius.**

Ante Meridiem (L. "Before Noon;" abbreviated A.M.).—The designation of the first twelve hours of the civil or nautical day; those, viz., before the sun has arrived at the meridian. The other twelve are distinguished as the hours "Post Meridiem."

Aphelion (Gk. ἀπὸ, "away from;" ἥλιος, "the sun").—Every planet revolves in an ellipse round the sun, situated in one of the foci. That point in its orbit farthest from the sun is called the *Aphelion*, that nearest to the sun the *Perihelion.*

Apogee (Gk. ἀπὸ, "away from;" γῆ, "the earth").—The moon revolves in an ellipse round the earth, situated in one of the foci. That point of her orbit farthest from the earth is called the *Apogee*, that nearest to the earth the *Perigee.*

Apparent (L. *apparēre,* "to appear").—An adjective indicating that which appears to the senses—phenomenal.

1. "*Apparent*" is sometimes equivalent to *true* or *real,* when contrasted with *fictitious* or *imaginary.* Thus the "apparent sun" is the *true* sun we see, as opposed to the *imaginary* "mean sun;" "apparent time" is reckoned by the hour-angles of the same sensible body opposed to "mean time," which is defined by the movement of the fictitious mean sun; "apparent noon" is when the true sun is on the meridian, and is

distinguished from the "mean noon," which is marked by the transit of the mean sun.

2. "*Apparent*" is sometimes used as a qualification, distinguishing on the one hand from *observed*, and on the other from *true*. It is in this sense applied to elements corrected for instrumental and circumstantial sources of error, but not yet reduced to the common standard for comparison and computation. We thus have the "apparent altitude" of a heavenly body, and the "apparent distance" of two heavenly bodies, distinguished on the one hand from the "observed," and on the other from the "true," altitude and distance. So also there is the "apparent place" of a heavenly body in the celestial concave, and the "true place."

3. "*Apparent*" is sometimes opposed to *proper*, to distinguish the phenomenal diurnal motion of the heavenly bodies resulting from the earth's rotation on her axis, from that which is due to the annual revolution of the earth in her orbit, and to the motion of each body in its orbit. —See under each term qualified.

"**Apparent Time of Change Tide.**"—The date of "change tide," which is expressed in *apparent* time. The simple term "change tide" is commonly used when speaking of this date.—See under **Tide.**

Approximations ; Approximate Method. — Approximations are approaches nearer and nearer to the quantity sought. An approximate method of solving many problems in navigation is one in which rough values of elements are used and general conclusions drawn. The results of an approximate method are often most valuable. It is frequently the only one that can be used in cases of haste; it may be conveniently applied when precision is not necessary; and it furnishes an easy check against mistakes which may occur in the more elaborate work of the rigorous method.

Aquarius, the Constellation of (L. "The Water-Bearer;" Gk. *ὑδροχοεὺς*, "The Water-Pourer").—The eleventh constellation of the ancient zodiac, indicating a wet season of the year. The number of visible stars in this group is very great, but they are all small. α *Aquarii*, mag. 3; 1882, R.A. 22^h, Dec. − 0° 54′.

Aquarius, the Sign of.—That portion of the ecliptic which extends from 300° to 330° longitude. Owing to the precession of the equinoxes, the *sign* does not now coincide with the *constellation* of this name, the sign at present occupying part of the constellations Capricornus and Aquarius. The sun is in Aquarius from about January 20th to about February 20th. Symbol ♒.

Aquila (L. "The Eagle").—A constellation containing an important star, α *Aquilæ*, formerly called *Altair*. It can readily be found by drawing a line from the two bright stars of Draco to Lyra, and continuing it to twice the distance. This is one of the stars of which the "lunar distances" are calculated and tabulated in the Nautical Almanac, and is therefore useful in finding the longitude. Mag. 1.2; 1882, R.A. $19^h\ 45^m$, Dec. + 8° 33′.

Arc (L. *arcus*, "a bow").—A portion of a curve, as of the circumference of a circle or ellipse.

Arc Proper.—The arc of an instrument for taking angles is graduated from zero through the range which the instrument is adapted to observe. This graduated arc is called "the arc proper."

Arc of Excess.—In instruments for taking angles, the zero of the arc is not coincident with its extremity, and the portion of the arc so excluded is graduated in an opposite direction to the arc proper: this portion is called "the arc of excess." It is necessary for finding the index correction. In observing small angles, if a pair of observations be taken, one directly and the other reversely, the mean of the readings, one "on" and the other "off" the arc, will give the angle free of index error. This is important in nautical surveying.

Arctic (Gk. ἄρκτος, *arktos*, "the bear").—A term synonymous with "northern," derived from the constellations of the Great Bear and the Little Bear, which are the most conspicuous of those adjacent to the north pole of the heavens.

Arctic Circle (Gk. ἄρκτος, "a bear").—The "*North Polar Circle*," or parallel of latitude of about 66° 32′ N. It encircles the north pole at the same distance from it as the tropical circles are from the equator (about 23° 28′), and it includes within it the north frigid zone, which it separates from the north temperate zone. The term was applied originally to the celestial parallel of declination of about 66° 32′ N., within which is situated the important constellation of the Great Bear.

Arcturus (ἄρκτος, "a bear;" οὖρος, "a warder," "The Bear-Keeper").—A bright star in the constellation Boötes, marked in modern catalogues *α Boötis*. This constellation Boötes, which used also to be called *Arctophylax* (ἄρκτος, "a bear;" φύλαξ, "a watcher"), is situated behind the tail of the Great Bear. Arcturus can easily be found by continuing the curve formed by the three stars of the Bear's tail, to almost twice its length. It is one of the stars observed to have a proper motion. Mag. 1, 1882, R.A, 14^{h} 10^{m}, Dec. + 19° 48′.

Argo (*Argo*, *Argûs*, the ship of Jason, the gentleman adventurer and navigator of mythical times).—A very extensive constellation of the southern hemisphere, of which the several parts are named, *Carina*, "the Keel;" *Puppis*, "the Poop;" *Malus*, "the Mast;" and *Vela*, "the Sails." It is to the south-east of Canis Major. The star *α Argûs* (called *Canopus*) is the brightest in the heavens after Sirius. Procyon, Sirius, and Canopus are in a line, running along the south-east of Orion, by which indication Canopus may be found; or a line from Rigel through *α Columbæ*, and produced about half the same distance, will terminate near Canopus; or again, it may be identified by the Sword of Orion which points directly towards it. Mag. 1; 1882, R.A. 6^{h} 21^{m}, Dec. —

52° 38′. η *Argûs* is a star remarkable for having recently changed from the second to the first magnitude. 1882, R.A. 10^h 40^m, Dec. – 59° 4′.

Argument (L. *argumentum*, "a reason").—In astronomical tables the argument is that quantity upon which the tabulated one depends, and with which, therefore, the table is "entered." Thus, in a table of correction for refraction, the altitude is the argument. When the element tabulated depends upon two given ones, then there are two arguments with which to enter the table—one at the side, the other at the top. Thus, for the correction for the moon's altitude, the arguments of the principal table are the apparent altitude and the minutes of the moon's horizontal parallax.

Aries, the Constellation of (L. *Aries*, "The Ram").—The first constellation of the ancient zodiac, marking the period for the commemoration of the mythical Golden Fleece connected with the ship Argo. The only two stars in it, of any note, are α and β near together in the horns, α being the more northerly. α *Arietis* (called *Hamel*) is one of the stars of which the "lunar distances" are calculated and tabulated in the Nautical Almanac, and therefore important for finding the longitude. Mag. 2; 1882, R.A. 2^h 1^m, Dec. + 22° 54′. β *Arietis*, Mag. 3.2; 1882, R.A. 1^h 48^m, Dec. + 20° 14′. The group can easily be found: either, by continuing the line from Procyon through Aldebaran to about the same distance beyond it, when it will traverse a little to the south of the two stars, passing by α first; or, the line joining the Pleiades and Algenib is bisected by β *Arietis*.

Aries, the Sign of.—The division of the ecliptic including the first 30° of longitude, reckoning from the vernal equinoctial point or first point of Aries. This origin, owing to the precession of the equinoxes, is at present in the constellation Pisces. The sun is in Aries from March 21st to April 20th. Symbol ♈.

Aries, First point of.—The "*Vernal Equinoctial Point,*" one of the points where the ecliptic crosses the equinoctial, so called as being the commencement of the sign Aries.—See **Equinoctial Points.**

Arithmetical Complement.—The complement of a quantity is what must be added to it to make it equal to some fixed quantity. In the case of numbers, the fixed quantity is generally 10, 100, or the power of 10 next higher than the number in question; thus the ar. co. of 756 is $1000 - 756 = 244$. The arithmetical complement of a logarithm is the difference between the logarithm and 10; thus the ar. co. of log. 4 is $10 - \log. 4 = 10 - {\cdot}602060 = 9{\cdot}397940$; the ar. co. of log. $\frac{1}{25}$ is $10 - \bar{2}{\cdot}602060 = 11{\cdot}397940$. In practice, the arithmetical complement of a logarithm (which is often wanted) is most easily found by taking each digit from 9 except the last significant one, which is to be taken from 10.—See **Complement.**

Artificial Horizon.—A reflector whose surface is perfectly horizontal, used for observing altitudes.—See **Horizon, Artificial.**

Artificial Projections.—Delineations of a surface on a plane traced according to fixed laws, but not being *perspective* representations. Example, Mercator's projection of the sphere. Distinguished from *Natural Projections.*—See **Projections.**

Astrolabe (Gk. ἀστὴρ, "a star;" λαμβάνειν, "to take"). A very ancient instrument for taking observations of the stars, the form of which has varied in different ages. Its principle rested upon the fact that the circles of the celestial concave and those of a small globe may be considered concentric, having the observer's eye in their common centre. The Astrolabe used by navigators was simply an annular disc graduated into 360°, and having a moveable diameter carrying vanes; the instrument being suspended by a ring at the point corresponding to the zenith. This, as Sir Jonas Moore says, "is the first and most natural instrument of all others," and, before the invention of the sextant, it was "no contemptible instrument."

"**Astronomical Bearings.**"—The method of finding the true bearing of a terrestrial object by referring it to some celestial body. The difference of bearing of the two being obtained, and the azimuth of the celestial body being known, the true bearing or azimuth of the terrestrial object can be determined.—See **Azimuth (True) of a Terrestrial Object, how found.**

Astronomical Clock.—A clock of superior construction, and specially adapted for astronomical observations.—See **Clock.**

Astronomical Day.—The day used by astronomers, and to which their observations are referred; it is distinguished from the *civil day*, which regulates the ordinary business of life.—See under **Day.**

Astronomy (Gr. *ἀστὴρ*, "a star," any celestial luminary; *νόμος*, "a law").—The science which treats of the great bodies which make up the visible universe. It is generally divided into (1) *Plane Astronomy*, which deals with the magnitudes, distances, arrangements, and motions of the heavenly bodies, as facts which are matters of observation; (2) *Physical Astronomy*, which investigates phenomena on the principles of mechanics, and refers them to general laws. That portion of Plane Astronomy which is applied to the purposes of navigation is called *Nautical Astronomy*. When this term is used to describe a branch of navigation, it is not a suitable one.—See **Celo-Navigation.**

Atmosphere (Gk. *ἀτμὸς*, "vapour;" *σφαῖρα*, "a sphere").—The mass of air enveloping the earth, and constituting a coating of equable or nearly equable thickness. This aërial ocean, of which the surface of the sea and land forms the bed, diminishes in density very rapidly, till, within a moderate distance from the earth, all sensible trace of its existence disappears. One-thirtieth of its whole mass is included within 1000 feet, and one-half of the whole within 18,000 feet, from the surface of the earth; and there is, practically speaking, no air at a distance above the earth's surface of the one-hundredth part of its diameter. There is probably an absolute and definite limit to the atmosphere. The atmosphere is always kept in a state of circulation owing to the excess of heat in its equatorial region over that at the poles, and clouds float in its lower strata. This is the special province of the meteorologist, whose observations, investigations, and inventions are of such importance to the seaman. The atmosphere is also a subject of important consideration for the mariner, by reason of its effect in modifying astronomical phenomena.—See under **Refraction**; **Twilight**.

Atmospheric Pressure.—The atmosphere presses equally in every direction; its effects therefore are not sensible upon bodies wholly immersed in it. But if the air be withdrawn from one side of a body, the pressure on the rest of the surface is at once made evident. In nature, we have illustrations of the working of this truth in the force which keeps the limpet on the rock and enables the fly to walk on the ceiling. Experiments have established the principle and given the actual amount of the pressure, which is found to be about 15 lb. on the square inch. Torricelli, in 1643, pointed out the column of mercury that could be kept in equilibrium by the pressure of the atmosphere, thus laying the foundation of the construction of the mercurial barometer. Pascal, by an experiment in 1648 upon the Puy de Dôme, demonstrated that the pressure decreases with the height above the surface of the earth. A partially inflated bladder was the simple instrument used, but the idea has been elaborated in the aneroid barometer.—See **Barometer.**

Augmentation of the Moon's Horizontal Semidiameter.—See under **Moon.**

Aurīga (L. " The Charioteer ").—A constellation containing five principal stars forming a great irregular pentagon. It is most easily found in connection with Gemini, its two brightest stars (α and β) forming a pair similar to Castor and Pollux, and lying alongside of Taurus as Gemini does near Orion ; also, as *Castor* is the upper star of the Twins, so *Capella* is the upper star of Auriga. *Capella* (*α Aurigæ*) is a very bright star, and can also be distinguished by having close to it a long isosceles triangle formed by three small stars. Mag. 1; 1882, R.A. $5^h\ 8^m$, Dec. + 45° 53′.

Autumnal Equinox (L. *autumnalis*, "pertaining to the autumn").—Relatively to the northern hemisphere, the Autumnal Equinox is that period when the sun crosses from the north to the south of the equinoctial; about September 23rd.—See **Equinoxes.**

Autumnal Equinoctial Point.—Relatively to the northern hemisphere, the Autumnal Equinoctial Point is the intersection of the ecliptic with the equinoctial, where the sun crosses from the north to the south of the equinoctial. It is more generally called "*The First Point of Libra.*"—See **Equinoctial Points.**

"**Auxiliary Angle A.**"—A subsidiary angle, the use of which facilitates the process of "clearing the distance" in finding the longitude by lunar. Let d be the true distance, d' the apparent distance; z the true zenith distance of the moon, v that of the other body; m' the apparent altitude of the moon, s' that of the other body. Then it may be deduced from the equation:

$$\frac{\cos d - \cos z \cos v}{\sin z \sin v} = \frac{\cos d' - \sin m' \sin s'}{\cos m' \cos s'}$$

that—

$$\cos d - \cos (z - v) = \left\{\cos d' + \cos (m' + s')\right\} \frac{\sin z \sin b}{\cos m' \cos s'},$$

Assume—

$$\frac{\sin z \sin v}{\cos m' \cos s'} = 2 \cos \mathrm{A}$$

Then—

$$2 \cos \mathrm{A} = \sin z \sin v \sec m' \sec s'$$

$$\mathrm{L.}\cos \mathrm{A} = \mathrm{L.}\sin z + \mathrm{L.}\sin v + \mathrm{L.}\sec m' + \mathrm{L.}\sec s' - 30{\cdot}301030$$

from which expression the values of A may be computed and formed into a table. In Inman, one table (Table W) gives "The Correction of the Moon's apparent Altitude and the Auxiliary Angle A," the arguments of which are the apparent altitude of the moon and the minutes of her horizontal parallax; additions being made dependent on the seconds of the horizontal parallax and the apparent altitude of the other body observed. By the use of this table, together with one of versines, *d* may be found with much less labour than by the usual rules of spherical trigonometry. —See **Lunar Distance, Clearing the.**

Axis (L. *axis*, "the axle-tree").—A straight line of reference with regard to position and phenomena. Thus we have, for defining the position of points, *co-ordinate axes*, and we have the *magnetic axis* of a bar of steel. The two principal applications of the term are with reference to the two cases respectively of *symmetry* and *rotation*. In a plane figure the axes are straight lines, on both sides of each of which the figure is symmetrical; each dividing the figure into two parts in such a manner that all perpendiculars to it, terminated by the boundary of the figure, are bisected in the axis. Upon such a line the figure has no tendency to turn in either direction, but if made to rotate, it will generate a solid, also symmetrical, about the same axis, for in such a solid all perpendiculars to the axis terminated by the boundary of the solid are bisected in the axis. Examples:—Every diameter of a circle is an axis, and if the circle be made to rotate about any one of them, a sphere will be generated having that diameter as axis. An ellipse has only two axes, the longest and shortest of its diameters, which are called the *major* and *minor axes;* if made to rotate about the major axis, a prolate spheroid will be generated; if about the minor axis, an oblate spheroid. The term axis, by its derivation, carries with it the idea of rotation, and in this view the following definition is comprehensive. The axis of a plane figure is a straight line which divides it into two such halves that if each were to rotate about this line they would both generate the same solid, and this solid has the same line for its axis.

Axis of the Earth.—That diameter upon which the earth rotates diurnally from west to east. In consequence of this rotation the earth has assumed its present form—an oblate spheroid, being compressed at the extremities of the axis (the poles), and bulging in the regions most remote from them (the equatorial). With reference to its extremities, the axis is called the "*Polar Diameter.*"

Axis of the Heavens.—That diameter about which the celestial concave appears to revolve diurnally from east to west. It passes through the observer's eye, and is parallel to the axis of the earth, with which it is generally considered coincident.

Azimuth (Arabic).—The following articles are arranged in a natural, instead of an alphabetical, order.

Azimuth of a Celestial Body.—The arc of the horizon intercepted between the north or south point and the circle of azimuth passing through the place of the body. Or it may be defined to be:—The angle at the zenith contained between the vertical circle passing through the elevated pole (the meridian), and the vertical circle passing through the object. Azimuth is usually reckoned from the north or south point eastward and westward from 0 to 180°. Sometimes the intersection of the horizon with that part of the meridian which is on the polar side of the zenith, is taken as the zero point; but Sir John F. W. Herschel recommends that, to avoid confusion, and to preserve consistency of interpretation when algebraic symbols are used (a point of essential importance), azimuth should be always reckoned *from* the point of the horizon *most remote* from the *elevated* pole *westward* (so as to agree in general directions with the apparent diurnal motions of the stars), and its reckoning be carried from 0 to 360° if always reckoned positive, considering the eastward reckoning as negative. Azimuth and altitude are the horizon co-ordinates for describing the points of the celestial concave relatively to the position of an observer on the earth's surface. When a body is *in* the horizon, the element used to define its position is the "amplitude," which is the complement of the azimuth in this case. Instead of this special term, the expression "Rising and Setting Azimuth" has been suggested.

Azimuth, Circles of.—Great circles of the celestial concave passing through the poles of the horizon, and so called because they severally mark out all points which have the same azimuth. They are also often called "*Vertical Circles,*" or simply "*Verticals,*" as passing through the "vertex" of the visible heavens; or "*Circles of Altitude,*" after the element that is measured, not *by* them, but *upon* them—the "altitude." Compare "Circles of Right Ascension," "Circles of Longitude."—See **Co-ordinates for the Surface of a Sphere.**

Azimuth of a Terrestrial Object.—The azimuth of an object is the angle between the meridian and the vertical circle passing through the object. On a horizontal plane, this angle is that between the "meridian line" and the line from the eye to the point of the compass on which the object is seen. The word *Azimuth* is, therefore, used not only of celestial objects, but of terrestrial ones also, though the more usual term in this case is "*Bearing.*" The azimuth of a ship's head is the same as her "*Course.*"

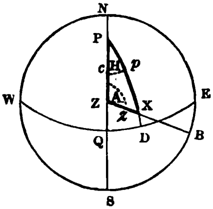
Azimuth, True.—The bearing of an object from the *true* north or south point; it is the azimuth found by calculation from the observed altitude or hour-angle of the body. It is in general simply called "*The Azimuth,*" but it is qualified as the *True* Azimuth to distinguish it from the *Compass* and *Magnetic* Azimuth.

Azimuth, Compass.—The bearing of the object from the compass north or south point; found by direct observation with an instrument carrying a magnetic needle. The difference between the true and compass azimuth gives the correction (variation and deviation combined) of the compass.

Azimuth, Magnetic.—A term sometimes used for the bearing of an object from the compass north or south point, found by direct observation with an instrument fitted with a magnetic needle, not affected by deviation. It is distinguished from the *True Azimuth*, or *Azimuth* properly so called, and from the *Compass* Azimuth. Since refraction and parallax take place vertically, they do not affect the observed magnetic azimuth of a body. In using the azimuth compass, the bearing of a celestial body is most conveniently observed when its altitude is low; it is also then less affected by any error in the verticality of the sight-vanes.

Azimuth Compass.—A compass specially adapted for observing bearings.—See **Compass, Azimuth Prismatic.**

Azimuth, how found by Calculation.—The figure is a projection on the horizon. NS is the meridian, EQW the equator, Z the Zenith, P the elevated pole, and X the body. Draw the circle of declination PXD, and the circle of altitude ZXB. SZB is the azimuth, and it can be found by determining the angle PZB, which is its supplement. In the triangle PZX, PX is the polar distance ($p = 90 \pm \delta$), PZ is the co-latitude ($c = 90 - l$), ZX is the zenith distance ($z = 90 - a$), ZPX is the hour-angle (H), and PZX the supplement of the azimuth ($A' = 180 - A$). A′ may be computed when any three of the other four parts are given (p, c, z, H). The latitude of the place and the declination of the body being known, the altitude of the body may be observed with a sextant, or its hour-angle may be deduced by noting the time by chronometer. The problem of finding the azimuth from the altitude is called "The Altitude Azimuth;" finding it from the hour-angle is called "The Time Azimuth."



1. "*The Altitude Azimuth.*"—Here we have the three parts, c, p, z,

$$\therefore \text{Sin}^2 \frac{A'}{2} = \frac{\sin \frac{1}{2}(p + \overline{c \sim z}) \sin \frac{1}{2}(p - \overline{c \sim z})}{\sin c \sin z}$$

$$\text{or hav } A' = \frac{\sqrt{\text{hav}(p + \overline{l \sim a})\,\text{hav}(p - \overline{l \sim a})}}{\cos l \cos a}$$

The latter formula in a logarithmic form becomes

$$\begin{aligned}\text{L.hav } A' = \text{L.sec } l + \text{L.sec } a - 20 &+ \tfrac{1}{2}\text{ L.hav }(p + \overline{l \sim a}) \\ &+ \tfrac{1}{2}\text{ L.hav }(p - \overline{l \sim a})\end{aligned}$$

Another convenient formula, and one easily remembered, is

$$\cos^2\frac{A}{2} = \frac{\sin S \sin (S - p)}{\sin c \sin z}$$

$$\text{when } S = \frac{p + c + z}{2}$$

2. "*The Time Azimuth.*"—Here we have the three parts, c, p, H, ∴.

(a) Using a subsidiary angle ϕ,

$$\left.\begin{aligned}\text{Tan } \phi &= \frac{\tan \delta}{\cos H} \\ \text{Tan } A' &= \frac{\tan H \cos \phi}{\sin (\phi - l)}\end{aligned}\right\}$$

(b) By the formulæ,

$$\left.\begin{aligned}\text{Tan } \tfrac{1}{2}(A' + X) &= \frac{\cos \frac{1}{2}(p - c)}{\cos \frac{1}{2}(p + c)} \text{ Cot } \frac{H}{2} \\ \text{Tan } \tfrac{1}{2}(A' - X) &= \frac{\sin \frac{1}{2}(p - c)}{\sin \frac{1}{2}(p + c)} \text{ Cot } \frac{H}{2} \\ A' &= \tfrac{1}{2}(A' + X) + \tfrac{1}{2}(A' - X).\end{aligned}\right\}$$

These, put into a logarithmic form, become

$$\text{L.tan } \tfrac{1}{2}(A' + X) = \text{L.cot } \frac{H}{2} + \text{L.cos } \tfrac{1}{2}(p - c) + \text{L.sec } \tfrac{1}{2}(p + c) - 20$$

$$\text{L.tan } \tfrac{1}{2}(A' - X) = \text{L.cot } \frac{H}{2} + \text{L.sin } \tfrac{1}{2}(p - c) + \text{L.cosec } \tfrac{1}{2}(p + c) - 20$$

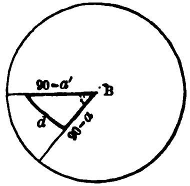
$$A' = \tfrac{1}{2}(A' + X) + \tfrac{1}{2}(A' - X).$$

The principal practical use of the above problem is to find the correction (variation and deviation combined) of the compass.—See **Compass, Corrections.**

Azimuth, the Altitude.—"The Altitude Azimuth" is the problem of computing the azimuth of a heavenly body from an observation of its *altitude*, having also given its declination and the latitude of the place of observation.—See **Azimuth, how found by Calculation** (1).

Azimuth, the Time.—"The Time Azimuth" is the problem of computing the azimuth of a heavenly body (the sun being usually chosen) from noting by chronometer its *hour-angle*, having also given its declination and the latitude of the place of observation. Time azimuths are the more generally useful than altitude azimuths as they can be observed when a ship is in port, or when any cause prevents the horizon being defined. The process, given above, of solving the spherical triangle is tedious, and it is practically superseded by Tables or Graphic Methods, which give the results within half a degree, or less.—See **Azimuth, how found by Calculation** (2).

Azimuth (True) of a Terrestrial Object, how found.—(1) By "Astronomical Bearings."—The true bearing of a terrestrial object may be determined by means of the *difference of bearing* between it and a celestial body, the true azimuth of the latter being easily computed. The difference of bearing might be observed directly, if we could observe with the compass the bearings of both the body and object at the same time. But in the cases which call for the application of this problem this cannot be well done, and therefore the difference of bearing is deduced by calculation, from the observed angular distance and the altitudes of the body and object. Let d be the distance of the body and object, a and a' their respective altitudes, and B their difference of bearing—then



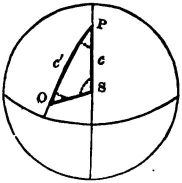
$$\text{Hav B} = \sqrt{\frac{\text{hav}\,(d + \overline{a - a'})\ \text{hav}\,(d - \overline{a - a'})}{\cos a \cos a'}}$$

$$\therefore\ \text{L.hav B} = \text{L.sec}\ a + \text{L.sec}\ a' - 20 + \tfrac{1}{2}\ \text{L.hav}\ (d + \overline{a - a'}) + \tfrac{1}{2}\ \text{L.hav}\ (d - \overline{a - a'}).$$

If the object is in the horizon,

$$\text{L.hav B} = \text{L.sec } a - 10 + \tfrac{1}{2}\,\text{L.hav } (d + a) + \tfrac{1}{2}\,\text{L.hav } (d - a).$$

(2) By "Geographical Position."—The true bearing or azimuth of a terrestrial object, as a mountain at a considerable distance, may be determined from its geographical position and that of the spectator. The true azimuth is the same as the *course on the great circle* from the spectator to the object, and this may be found by the usual rule. If c and c' are the co-latitudes of the spectator and object, P their difference of longitudes, S the true bearing of the object from the spectator, O the true bearing of the spectator from the object—then



$$\left.\begin{aligned} \text{Tan } \tfrac{1}{2}(\text{S} + \text{O}) &= \frac{\cos \frac{1}{2}(c \sim c')}{\cos \frac{1}{2}(c + c')} \text{Cot } \frac{\text{P}}{2} \\ \text{Tan } \tfrac{1}{2}(\text{S} - \text{O}) &= \frac{\sin \frac{1}{2}(c \sim c')}{\sin \frac{1}{2}(c + c')} \text{Cot } \frac{\text{P}}{2} \\ \text{S} &= \tfrac{1}{2}(\text{S} + \text{O}) + \tfrac{1}{2}(\text{S} - \text{O}). \end{aligned}\right\}$$

$$\therefore \text{L.tan } \tfrac{1}{2}(\text{S} + \text{O}) = \text{L.cot } \frac{\text{P}}{2} + \text{L.cos } \tfrac{1}{2}(c - c') + \text{L.sec } \tfrac{1}{2}(c - c') - 20$$

$$\text{L.tan } \tfrac{1}{2}(\text{S} - \text{O}) = \text{L.cot } \frac{\text{P}}{2} + \text{L.sin } \tfrac{1}{2}(c - c') + \text{L.cosec } \tfrac{1}{2}(c - c') - 20$$

$$\text{S} = \tfrac{1}{2}(\text{S} + \text{O}) + \tfrac{1}{2}(\text{S} - \text{O}).$$

This problem is sometimes of use for finding the correction (variation and deviation combined) of the compass.

Azimuth Diagram, Godfray's.—A diagram by means of which the true azimuth can be rapidly and simply obtained without calculation, the data being the *latitude*, the *sun's declination*, and the *apparent time*. It is engraved by the Hydrographic Office, Admiralty. The scale on which it is constructed gives the result to within one-eighth of a degree. A full explanation accompanies the diagram.

Azimuth Tables.—The two following works will be found most useful to the practical navigator.

1. Sun's True Bearing or Azimuth Tables, computed for intervals of four minutes, between the parallels of 30° N. and 30° S. inclusive, with Variation Chart; also Instructions for using the Tables in Danish, Dutch, French, German, Italian, Portuguese, Russian, and Spanish. By Captain John E. Davis, R.N., F.R.G.S., of the Hydrographic Department, Admiralty; and Percy L. H. Davis, F.R.A.S., Nautical Almanac Office. Price 10*s*. 6*d*.

2. Sun's True Bearing or Azimuth Tables, computed for intervals of four minutes, between the parallels of latitude 30° and 60° inclusive. By John Burdwood, Staff Commander, R.N., late Naval Assistant in the Hydrographic Department, Admiralty. Price 4*s*. 6*d*.

Azimuth and Altitude.—The horizon co-ordinates for defining points of the celestial concave in its diurnal revolution, relatively to the position of an observer on the earth's surface. Azimuth is measured on the horizon from the north or south point (that most remote from the elevated pole) westward through 360°, or westward and eastward from 0 to 180°; altitude is measured on the secondaries of the horizon (which are hence called "Circles of Altitude") positively to the zenith, and negatively to the nadir.—See **Co-ordinates for the Celestial Sphere.**

Azimuth and Altitude Instrument.—An instrument for taking azimuths and altitudes simultaneously. It is adapted for use on shore as in marine surveying, the form most generally used being that called the *Theodolite*. We shall here only mention the general principle of all such compound instruments. The telescope, by which the observations are made, is capable of motion in two planes at right angles to each other, and the amount of its angular motion in each is measured on two circles, co-ordinate to each other, whose planes are parallel to those in which the telescope moves. In the azimuth and altitude instrument one of these planes is horizontal, the other vertical. This instrument is known as the "alt-azimuth."

Azimuth, Motion in.—An instrument is said to move "in azimuth" when it is turned on a vertical axis; in contradistinction, it is said to move "in altitude" when it is turned on a horizontal axis. An azimuth and altitude instrument admits of both motions.

B.

b.—Among the letters used in the log-book to register the state of the weather, b denotes *Blue Sky*, whether with clear or hazy atmosphere.

"Backing" of the Wind.—The wind is said to "back" when it appears to shift against the sun's course. It is a sign of more wind or bad weather.

Back-staff.—A form of the quadrant for taking the altitude of the sun at sea, in use before the invention of reflecting instruments. It was the contrivance of Captain John Davis, about 1590, and was called after him, "*Davis's Quadrant*," but was known to the French as the "*English Quadrant*." It consisted of two concentric arcs, carrying at their common centre the horizon-vane; the arc of larger radius was of 25° or 30°, and carried the sight-vane. Fixed to the upper radius of this was an arc of smaller radius and of 65° or 60°, carrying the shadow-vane. The two arcs together subtended an angle of 90°; hence the instrument was a *Quadrant*. When taking an altitude, the observer stood with his back to the sun, and marked, through the sight-vane on the 30° arc, the coincidence of the shadow of the vane on the 60° arc turned towards the sun, with the vane pointed to the horizon. Hence the name "*Back-staff*."

Barometer (Gk. *βάρος*, "weight," "pressure;" *μετρεῖν*, "to measure"). —An instrument for measuring the weight or pressure of the air. It indicates whether that pressure is becoming greater or less, or remaining stationary [**Atmospheric Pressure**]. The word "weight" is rather misleading. Strictly speaking, the barometer measures the *elastic force* of the atmosphere; with weight or density it is concerned only as they are functions of elastic force. There are two kinds of barometers.

Fig. 1.

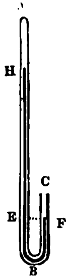
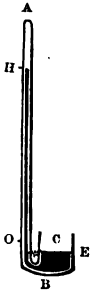


Fig. 2.



I. **The Fluid Barometer.**—The discovery of the fluid barometer was the result of a question proposed by the pump-makers to Galileo—"How is it that water will not rise in the pipe of the pump (exhausted of air) more than about 32 feet?" Galileo's pupil, Torricelli, drew practical conclusions from the fact that this 32 feet is the height of a column of water which counterpoises the weight of the atmosphere. If this were so, he reasoned that a shorter column of a heavier fluid would suffice, and experimentalized with mercury. He filled a tube of about 36 inches long, and open at one end only, with mercury, and, stopping the open end with his finger, inverted the tube in an open vessel of the same fluid. On removing the finger, the mercury in the tube sank in the tube to about 28 inches higher than that in the reservoir. This was the first mercurial barometer; date, 1645. Of the different forms of the *Mercurial Barometer* we shall only notice three:—1. The *Siphon Barometer*, called so from its shape (Fig. 1). A bent glass tube ABC, closed at one end, has its longer leg AB filled with mercury, and is then placed in a vertical position. The mercury will descend in AB, and rise in BC, leaving a vacuum above its surface in AB. Let H and F be the upper and lower surfaces of the mercury in the two branches; draw through F the horizontal line EF. Then the pressures of the portions of mercury in the parts BE, BF balancing one another, EH is the column whose pressure counterpoises the pressure of the atmosphere, and its varying height indicates changes in that pressure. 2. The

Common or *Cistern Barometer* (Fig. 2). This consists of a vertical closed tube AB leading into an open vessel, BC, and a scale of inches attached to AB. This scale being fixed, the height of the mercurial column indicated is the height above a fixed horizontal plane (O) not above the level (E) of the mercury in BC, which is variable. Hence the height read off will be in error; but this error is rendered small by the area of the reservoir BC being much greater than that of the tube AB. The error may be easily calculated. 3. The *Marine Barometer*, first constructed by M. Passement in 1758. In this instrument the diameter of the reservoir is about 1¼ inches, and that of the tube about ¼ inch. The scale, instead of being divided exactly into inches, as in the common barometer, is shortened in the proportion of about ·04 of an inch for every inch, which obviates the necessity of applying the error above noticed. But the distinctive feature of the marine barometer is the contrivance for guarding against the effects of the motion of the ship—the "pumping" of the mercury. The tube is contracted to a very small bore through a few inches. When first suspended, the mercury is in consequence as much as twenty minutes in falling from the top of the tube to its proper level. This contraction of the tube causes the marine barometer, when used on shore, to be a little behind the common barometer, to an amount varying according to the rate the mercury is rising or falling, being at times ·02 of an inch.

II. The **Aneroid Barometer.**—In the aneroid barometer (the invention of M. Vidi, of Paris), the varying pressure of the atmosphere is indicated, not by the varying height of a column of fluid, but by the compression and expansion of a small metal vessel from which nearly all the air has been exhausted, and which is kept from collapsing by a spring. Hence the name (Gk. ἀ, "without;" *νηρός*, "fluid"). The external appearance of this instrument is that of a circular brass box, having a dial face, the graduations on which are pointed out by a finger. This finger is moved by machinery attached to the elastic nearly exhausted vessel fixed within. At the back of the instrument is a screw, for the purpose of adjusting its indications by reference to the mercurial barometer. The aneroid requires to be thus originally set, and should be thus adjusted from time to time. This instrument possesses the advantages of being very susceptible and portable, and is a most convenient " weather-wiser " for ship use. It is also a convenient instrument for roughly estimating the heights of mountains.

The principal use of the barometer, especially to the navigator, is that, combined with a thermometer and hygrometer, it forms a *weather-glass*. The barometer indicates the changes in pressure, the thermometer the changes in temperature, and the hygrometer the changes in moisture. Combined, they give the state of the air, and this foretells coming weather. We shall here simply state the circumstances which affect the barometer—(1) The direction of the wind; a northerly wind in north latitudes, and a southerly in south latitudes, tending to raise it most, and the opposite wind in each case to lower it most; (2) The moisture of the wind—moisture and a falling barometer are connected; (3) The force of the wind—the greater the force the greater the fall; (4) Electricity—effects uncertain.—See **Weather-Glass.**

Bearing.—The bearing of an object or place is the angle contained between the meridian and the vertical plane through the object. It is the same as the *course* to the place.

Bearing, Compass.—The bearing of an object as observed by the compass. It is the angle between the needle of the standard compass on board the ship of the observer and the direction of the object; it is, therefore, affected by the deviation and variation of the compass. If the correction for deviation be applied, the *True Magnetic Bearing* is obtained; and if, further, the correction for variation be applied, the *True Bearing* or *Azimuth* is deduced.

Bearing, Magnetic.—The Magnetic Bearing, or " *True Magnetic Bearing*," or " *Correct Magnetic Bearing* " of an object is the angle which its direction makes with the magnetic meridian. This is the bearing which is observed with the azimuth compass after being corrected for local deviation; from it the *True Bearing* is deduced by applying the correction for variation.

Bearing, True.—The true bearing of an object, or the "*Bearing*" properly so called, is the angle which the direction of the object makes with the meridian. It is thus qualified to distinguish it from the *Compass* and *Magnetic Bearings.*—See **Azimuth.**

Bearings, Astronomical.—The method of finding the true bearing of a terrestrial object, by referring it to some celestial body whose azimuth is known, is described as "Astronomical Bearings," which see.

Bearing, Geographical.—The method of determining the true bearing of a terrestrial object (as a mountain at a considerable distance) from its known geographical position and that of the spectator. The problem is the same as finding the course on the great circle.

Bearing, taking a.—Taking a bearing of an object is technically called "setting" the object.

Bearings, Cross.—"Cross Bearings" are the bearings of two or more objects taken from the same place, and therefore intersecting or "crossing" each other at the station of the observer. When near a coast where the landmarks are well laid down on the chart, cross bearings give the position with ease and accuracy.

Bearings, Reciprocal.—The bearings of two compasses each taken from the other.—See **Swinging the Ship.**

Bearing, Line of.—If a ship is in the vicinity of land, one "*Circle of Equal Altitude*" [**Sumner's Method**] is often of great use to the navigator who is uncertain of his exact position. He is on some point of this circle, but where he does not know. Let him project it on his chart and produce the resulting line till it meets or passes near the land. Such a line is called a "Line of Bearing." If it hit any prominent mark or light, the *bearing* of this is known, and by sailing along the line of bearing till the object is sighted, the exact position of the ship may be picked up. The line of bearing may cross the range of a lighthouse, and consequently, when the light is first sighted, the exact position of the ship is known. Or the position on the line of bearing may be found by soundings. When the coast trends parallel to the line of bearing, the distance of the ship from the shore is indicated, though her absolute position is uncertain.

Bellatrix (L. "warlike").—The name for the bright star γ *Orionis.*—See **Orion.**

Betelguese or **Betelgeux.**—The name for the bright star α *Orionis.*—See **Orion.**

Binnacle (formerly **Bittacle,** from Bitts). The turret-like cover to the compass on deck; it is glazed and furnished with suitable lamps. The "Binnacle Compass" is often the name used for the compass placed in a commanding position, at which the pilot stands to "con" the vessel, in contradistinction to the "steering compass," which is situated before the helmsman. There is, however, a binnacle-cover for all the compasses.

Bissextile (L. *bis,* "twice;" *sextus,* "sixth").—"*Leap Year.*" In the Julian calendar every fourth year consisted of 366 days, instead of 365. The additional day was intercalated or inserted after the 24th of February, which in the Roman calendar was reckoned as *sexto Calendas Martii,* "the *sixth* day before the Calends of March;" every fourth year this day was repeated as the *bis sexto Calendas Martii,* the added day being called the *bissextus dies.* The year was hence named *Bissextilis.*

Boötes (Gk. βοώτης, "a ploughman").—The name, as ancient as the Homeric age, of the constellation following the Great Bear, which, it is probable, was originally figured as an ox or waggon. Boötes is also called *Arctophylax*, "the Bear-Watcher;" and the one bright star in the group, *α Boötis*, is named *Arcturus*, which has a similar meaning, "the Bear-Keeper." *α Bootis* can easily be found by continuing the curve formed by the three stars of the Bear's tail to about twice its length. It is one of the stars observed to have a proper motion. Mag. 1; 1882, R.A. $14^h\ 10^m$, Dec. + 19° 48′.

Borda's Circle.—A repeating reflecting circle, constructed by the eminent French surveyor Jean Charles Borda (died 1799). Borda introduced into the French naval surveys the use of reflecting instruments, instead of determining positions by compass-bearings. He improved upon Mayer's Reflecting Circle, and invented the "principle of repetition." Theoretically this method of observing reduces the effect of errors of graduation of the instrument to any extent, but there is some practical obstacle to any satisfactory realization of this result.—See under **Circle.**

Bore (a word imitative of the sound produced, like the Anglo-Saxon *To bore*. Compare the other names for the phenomenon—French, *Barre;* Brazilian, *Pororóca;* English, *Eagre* or *Hygre;* Dutch, *Agger*. Sometimes the word is written *Boar* or *Boar's Hear*, and then an analogy to the rushing career of that animal is suggested).—The form the tide-wave assumes at spring-tides in certain estuaries and rivers. As the tide enters and advances the wave acquires a considerable elevation, with an abrupt, broken face, and rushes up violently against the current with a hollow and harsh roar. Among other places the phenomenon is seen in the Severn, the Garonne, and the Bay of Fundy. In some of the rivers of Brazil this tide-wave rises to the height of from 12 to 16 feet, and in the Hoogly it travels at the rate of above 17 miles an hour. The conditions necessary for the formation of the bore are:—First, a very large tide rising with great rapidity; and, secondly, that the river be bordered with a great extent of flat sands near the level of low water, the channel contracting gradually from an estuary. Attention to the bore in different places is of great importance to the seaman in anchoring ships and in boat duties. Thus no boat ventures to navigate the channels between the islands at the mouth of the Brahmapootra at spring-tide; in the Hoogly, at Calcutta, the bore running along one bank only, on its approach the smaller shipping are removed to the other side, or ride it out in mid-stream; and in some of the rivers of Brazil the barges, at the spring-tides, are always moored in deep water, it being noticed that the bore is only dangerous on the shoals.

Breakers.—Waves whose crests are broken. They are among the signs of the near approach to land. The depth of water, however, at which they appear is uncertain, and it is often difficult to distinguish between breakers and "topping seas."

Boxing the Compass.—Repeating the points of the compass in any order.

Buys-Ballot Law.—The law of wind rotation as extended by Buys-Ballot. It is as follows:—If there be a difference between the barometric readings at any two stations, the wind will blow at right angles to the line joining them; the observer with his back to the wind will have the place where the reading is lowest on his left-hand side in the northern hemisphere, but on his right-hand side in the southern hemisphere.

C.

c.—Among the letters used in the log-book to register the state of the weather, **c** denotes "cloudy"—*i.e.* detached opening clouds.

Cable.—As a measure used in marine surveying a cable is $\frac{1}{10}$ nautical mile, which is estimated roundly at 6000 feet. Thus, 1 cable = 100 fathoms = 600 feet.

Calendar (L. *Calendarium*, *Calendæ*, the first day of each month, from *calāre*, "to call," "summon").—The regulation, arrangement, and register of civil time. The ancient Roman calendar is the original of those used throughout Europe. The natural unit for shorter durations adapted to the immediate wants and ordinary occupations of man is the *solar day*, or period of the sun's successive arrivals at a given meridian. It varies in length during the course of a year, but the variation is socially unimportant, and the tacit adoption of its *mean value* from the earliest ages arose probably from ignorance that such fluctuation existed. This *mean solar* or *civil* day is divided into 24 hours. The unit for longer durations again is naturally the period in which recur the seasons on which depend all the vital business of life. It is the interval between two successive arrivals of the sun at the vernal equinox, and is called the *tropical year*. This period varies slightly, and is incommensurate with the lesser unit, its length being about $365^d\ 5^h\ 58^m\ 59{\cdot}7^s$. Now, if the odd hours, minutes, etc., were to be neglected, and the *civil year* made to consist of 365^d, the seasons would soon cease to correspond to the same months, and would run the round of the whole year; this odd time must therefore be taken account of. But then, again, it would be very inconvenient to have the same day belonging to two different years. To obviate this difficulty, a very neat contrivance was inaugurated by Julius Cæsar by the advice of the astronomer Sosigenes. He introduced a system of *two* artificial years, one of 365 and the other of 366 integer days; three consecutive years consisting of 365, and then a fourth year of 366 days. The odd months each consisted of 31 days, and the even months of 30 days except February, which had only 29 days; on every fourth year February also had the regular 30. This simple arrangement was soon disturbed, in flattery to Augustus, by assigning the same number of days to the month named after him as was contained in that named after Julius Cæsar. The longer years were called "bissextile" or "leap-years," and the surplus days formed of the accumulated fractions and thrown into the reckoning were called "intercalary" or "leap-days." This calendar made the average length of civil years 365^d 6^h, which was only a rough approximation to the truth, and the error soon accumulated to a whole day. A reformation was effected by Pope Gregory XIII. in 1582. He suppressed 10 days of the calendar, thus restoring the vernal equinox to the 21st March, the day on which it fell at the date of the Council of Nice, 325. His law for the future regulation of the succession of the short and long years is as follows:—Every year whose number is not divisible by 4 without remainder consists of 365 days; every year which *is* so divisible, but is not divisible by 100, of 366 days; every year divisible by 100, but not by 400, again of 365; and every year divisible by 400 again of 366 days. It may be conveniently remembered thus:—Every year whose number does not end with 00 and is divisible by 4 is a leap-year, and every year whose number ends with 00 and is divisible by 400 is a leap-year. The error in the Gregorian reckoning amounts only to one day in 3860 years. For the period of 10,000 years the average length of the Gregorian years is $365{\cdot}2425^d$ (according to Delambre's tables). The Protestant countries of Europe were long before they adopted this reform, and it was not introduced into England till 1752. The "old style" was then abolished by Act of Parliament. The rectification was effected by dropping 11 days and enacting that the day following 2nd September, 1752, should be called 14th September.

Cancer, Constellation of (L. *Cancer*, "The Crab").—The fourth constellation of the ancient zodiac, lying between Gemini and Leo. There is no star in it above the fourth magnitude.

Cancer, Sign of.—The fourth division of the ecliptic, including from 90° to 120° of longitude. Owing to the precession of the equinoxes, the *constellation* Cancer is no longer in the *sign* of the name, the constellation Gemini having taken its place. The sun is in Cancer from about June 21st, when he arrives at his greatest northern declination, to about July

22nd. The *First Point of Cancer* is known as the summer solstice in the northern hemisphere. Symbol ♋.

Cancer, Tropic of.—That parallel in the northern hemisphere whose latitude is equal to the sun's greatest declination, about 23° 28′.

Canes Venatĭci (L. "The Hunting Dogs").—A constellation between Ursa Major and Boötes. The two dogs are named *Asterion* and *Chara.* The principal star is marked *α Canum Venaticorum,* named also *Cor Cároli,* and may be found by drawing a line from Dubhe, the star of the Great Bear nearest the pole, to the opposite star of the square of that constellation, and producing it to nearly twice the distance. Mag. 3; 1882, R.A. $12^h\ 51^m$, Dec. + 38° 57′.

Canis Major (L. "The Greater Dog").—A constellation to the S.E. of Orion, containing the brightest star in the heavens, *α Canis Majoris. α Canis Majoris,* the Dog Star, is also called *Sirius;* it can easily be found by continuing the line of the belt of Orion to about three times its length. Mag. 1; 1882, R.A. $6^h\ 40^m$, Dec. − 16° 33′.

Canis Minor (L. "The Lesser Dog").—A constellation to the E. of Orion, containing a bright star, *α Canis Minoris,* called also *Prócyon.* It can be easily found by continuing a line through the upper two stars of Orion to about twice its length. Mag. 1; 1882, R.A. $7^h\ 33^m$, Dec. + 5° 32′.

Canópus.—The name of the bright star *α Argûs.* Called after a place in Egypt.—See **Argo.**

Capella (L. "The Kid").—The name of the bright star *α Aurigæ.*—See **Auriga.**

Capricornus, Constellation of (L. *Capricornus,* "The Goat").—The tenth constellation of the ancient zodiac, lying between Sagittarius and Aquarius. There is no star in it above the third magnitude; *α* and *β* may be found by the line joining Lyra and Altair being produced to not quite its own length.

Capricornus, Sign of.—The tenth division of the ecliptic, including from 270° to 300° of longitude. In consequence of the precession of the equinoxes, the *constellation* of Capricorn is no longer in the *sign* of this name, the constellation Sagittarius having taken its place. The sun is in Capricorn from about December 21st to about January 20th. *The First Point of Capricorn* is known as the *Winter Solstice* in the northern hemisphere. Symbol ♑.

Capricorn, Tropic of.—That parallel in the southern hemisphere whose latitude is equal to the sun's greatest declination, about 23° 28′.—See **Tropics.**

Cardinal (L. *cardinalis*, literally, "pertaining to a hinge," *cardo*, hence that on which other things turn, "principal").—The points to which, as regards position and motion, others are referred. Thus we have "the Cardinal Points of the Compass," "the Cardinal Points of the Horizon," "the Cardinal Points of the Ecliptic."

Cardinal Points of the Compass.—The same as the cardinal points of the horizon, but with reference to the direction of the magnetic needle. They are named *North*, *South*, *East*, and *West;* the most important of which is the North.

Cardinal Points of the Horizon.—The four cardinal points of the horizon are the *North* (N.), *South* (S.), *East* (E.), and *West* (W.). The north and south points are where the meridian intersects the horizon, and they are the poles of the prime vertical; the east and west points are where the prime vertical intersects the horizon, and are the poles of the meridian. The north and south points are those from which the horizontal distance from the meridian of all bodies having an altitude is measured; the east point is that to which their rising, and the west point that to which their setting is referred.

Cardinal Points of the Ecliptic.—The four cardinal points of the ecliptic are the two points of its intersection with the equinoctial, called the *Equinoctial Points*; and the two points where it attains its greatest distance from the equinoctial, called the *Solstitial Points.* With reference to the seasons of the northern hemisphere, these are named the *Vernal* and *Autumnal Equinoctial Points*, and the *Summer* and *Winter Solstitial Points*. These are more commonly called after the signs of the ecliptic in which they are severally situated; the *First Point of Aries* (symbol ♈) and the *First Point of Libra* (♎), the *First Point of Cancer* (♋) and the *First Point of Capricorn* (♑). The Colures intersect the ecliptic in these four points. The most important of them is the First Point of Aries, as from it right ascensions and longitudes are reckoned. The sun is in ♈ about March 21st, in ♋ about June 21st, in ♎ about September 21st, and in ♑ about December 21st.

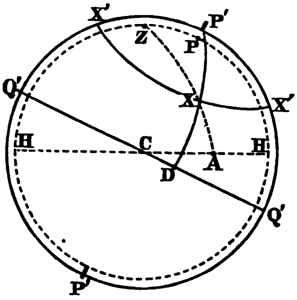
Cassiopeia (named after the mythical wife of Cepheus).—A constellation on the opposite side of the pole to the Great Bear, and at about the same distance from it. It consists of a group of stars of the third and fourth magnitude, disposed in a form somewhat resembling a chair, or the letter W. *α Cassiopeiæ* is, of the six principal stars, the farthest from the pole. Mag. 2.3 (var.); 1882, R.A. $0^h\ 34^m$, Dec. + 55° 53′.

Castor.—The name of the bright star *α Geminorum.*—See **Gemini.**

Celestial.— (L. *cœlestis*, from *cœlum*, "the heavens").—Pertaining to the heavens; opposed to *terrestrial*, pertaining to the earth. Thus we have the "celestial meridian" of an observer, and the "celestial horizon," as distinguished from his "terrestrial meridian" and "terrestrial horizon;" the "celestial equator," as distinguished from the "terrestrial equator;" "celestial longitude and latitude," and "terrestrial longitude and latitude."—See under each noun qualified.

Celestial Concave (L. *concăvus*, "hollow").—Of the two spherical surfaces with which we are concerned, the terrestrial sphere is *convex—i.e.* presents its external surface to us; while the celestial sphere is *concave—i.e.* presents its internal surface to us. The latter is an imaginary surface. The different heavenly bodies are interspersed in space at various distances from the earth, but to a spectator on its surface all of them appear (in consequence of the constitution of our organ of vision) to be placed or projected on the interior surface of a hollow sphere of infinite magnitude, its centre being the centre of the earth, which is considered coincident with the position of the observer. This is called the "*Celestial Concave*," the "*Sphere of the Heavens*," or "*Sphere of the Stars*." It must always be remembered that the spherical dome above us is an appearance only, arising in the mind of a spectator of the heavens from association with the real concave surface of the retina of his eye, which is the true seat of all visible angular dimensions and angular motion. This celestial concave, with its radius infinite compared with all terrestrial distances, is a confusing conception when problems are concerned. But all ambiguity will be dispelled if we bear in mind that Nautical Astronomy is concerned not with actual but with *angular* distances of the heavenly bodies; plane and dihedral angles subtended at the eye being involved. The only purpose the celestial concave subserves is that it enables us to substitute spherical triangles for solid angles. The radius of this sphere is perfectly arbitrary, and may be taken great or small, the eye of the spectator being supposed, as he changes his position, to occupy the centre. This point is fully explained in a paper by the author in *Naval Science*, January, 1873, "The Definitions of Nautical Astronomy Systematized."

Celestial Concave, Motion of.—With respect to the motion of the celestial concave, its points and circles fall under two divisions—those which are dependent upon the observer's position, and those which are the same wherever he is stationed. To meet the difficulty thus created, we may imagine an inner transparent surface to the celestial concave in



rigid connection with the earth, on which, projected from the centre of the earth C, are the observer's station giving us the zenith Z, and the great circle of which it is the pole—the horizon HAH. The position of Z determines also the meridian ZPH of the observer. All these are considered as fixed with the observer, and marked down upon the inner transparent shell of the celestial concave. On the outer surface, all those points (the stars, centre of sun, etc., and imaginary circles connected with them) are projected which are independent of the observer's position; and this surface is conceived to revolve diurnally about its axis PP', carrying with it these points and circles, and sweeping them across the points and circles of the inner fixed surface. These fixed circles are what are represented by the broad horizontal wooden rim and brazen meridian of the old artificial celestial globe, and by the metrosphère of the modern French navisphère.

Celo-Navigation (L. *cœlum*, "the heavens," from Gk. *κοῖλον*, "hollow"). —A term I have proposed for that branch of the science of navigation in which the place of a ship at sea is determined by finding the zenith of the place from observations of the heavenly bodies. The other branch, in which the position of the ship is determined by referring it to some other spot on the surface of the earth, we distinguish as *Geo-navigation*. There is some difficulty in deciding upon the best prefix for this much-needed term. *Urano* (Gk. *οὐρᾰνὸς*, "the vault of heaven") would be more critically correct as antithetical to *Geo* (Gk. *γῆ*, "the earth"), as in the terms "geography" and "uranography," but the resulting compound would be cacophonous and inconvenient. *Astra* (Gk. *ἄστρα*, "the stars"), the prefix of "astronomy," suggests itself, but this has reference to the heavenly bodies, whereas we are concerned also with imaginary points of the celestial concave. The only objection to *celo* is that it is directly derived from the Latin, while that to which it is opposed, *geo*, is directly from the Greek; but, besides that this Latin word is of Greek origin, this slight objection is outweighed by the appropriateness and brevity of the prefix, and its analogy to the familiar term, "celestial concave." What we here distinguish as Celo-navigation has hitherto been commonly known as "*Nautical Astronomy.*" The term "nautical astronomy," however, implies a branch of the science of astronomy, just as "nautical geography" would imply a branch of the science of geography; whereas we are speaking of a branch of the science of navigation.—For a fuller notice of Celo-navigation, see under **Navigation.**

Centaurus (L. "The Centaur").—A constellation which, together with Crux, constitutes a bright group in the southern hemisphere, pointed out by the line joining Arcturus and Spica. The two principal stars, α^2 and β of the Centaur, are close together, β being the nearer to the cross. α^2 *Centauri*, mag. 1; 1882, R.A. $14^h\ 32^m$, Dec. − 60° 21′. β *Centauri*, mag. 1; 1882, R.A. $13^h\ 56^m$, Dec. − 59° 48′.

Centigrade (L. *centum*, "a hundred;" *gradus*, "a step," "graduation").—A centigrade scale is one in which the unit is divided into a hundred equal parts or *grades*. The term is best known as applied to Celsius's thermometer, which is graduated with a hundred degrees between the freezing and boiling points.—See **Thermometer.**

Centimètre (L. *centum*, "a hundred;" Fr. *mètre*).—A French measure the one-hundredth part of the mètre, and equal to ·394, or about ⅖ of an English inch.—See **Mètre.**

Central Latitude.—The angle which the line joining the station of the observer with the "centre" of the earth makes with the plane of the equator, as distinguished from the angle which the vertical line at the place makes with the plane of the equator. The more commonly recognized term for this is "*Geocentric Latitude,*" but there are several objections to it. In speaking of *terrestrial* latitudes, the *geo* is redundant; and again, the adjective *geocentric*, in opposition to *heliocentric*, is applied to *celestial* latitudes, and it would be well to restrict it to so appropriate a usage. We prefer the terms *central* and *normal* latitude.—See **Latitude of an Observer.**

Central Projection of the Sphere.—A natural projection on a tangential plane as primitive, the eye being at the "centre" of the sphere. It is also called the "*Gnomonic Projection.*"—See **Projection.**

Cetus (L. "The Whale").—A constellation to the south of Aries. It contains two principal stars α and β. α *Ceti*, called *Menkar*, is in the vertex towards the S.W. of an isosceles triangle, at the angles of whose base are the Hyades and Pleiades. Mag. 2.3; 1882, R.A. $2^h\ 56^m$, Dec. + 3° 38′. β *Ceti* is found by joining Aldebaran and Menkar, and producing the line to nearly twice the length. Mag. 2; 1882, R.A. $0^h\ 38^m$, Dec. − 18° 38′.

Chain.—The unit employed in the actual measurement of lengths by surveyors. The land-surveyor's or Gunter's chain consists of 100 links = 4 poles = 22 yards = 66 feet. The marine surveying chain, which is also sometimes used by builders, is 100 feet in length.

Change of the Moon.—The phenomenon which takes place when the moon and sun are in conjunction, at which time the moon commences afresh to go through its phases. The term is sometimes loosely applied to the transition from any one *quarter* to the next.—See **Lunation.**

Change Tide.—The tide, high water of which takes place on the afternoon of the day the moon "changes" or is at the full, more especially if the moon happens to change at noon, or is full at midnight.—See under **Tide.**

Chart (L. *charta*, from Gk. χάρτης, "a leaf of paper").—The map of the hydrographer. Navigation would be impossible without the chart, and its construction has especial reference to the requirements of the navigator. The use to be made of the chart in each case determines the method of projection, and the particulars to be inserted. (1) Thus the chart may be required for coasting purposes, for the use of the pilot, etc., and then, only a very small portion of the earth's surface being represented at once, no practical error results from considering that surface a plane, and a "*plane chart*" is constructed, in which the different headlands, lighthouses, etc., are laid down according to their bearings. The soundings are marked in these charts with great accuracy; the rocks, banks, and shoals, the channels with their buoys, the local currents, and circumstances connected with the tides, are also noted. (2) Again, for making long sea-passages, the navigator wants a chart on which his course may be conveniently marked down. Now if he sails for any time on the same course, which is a practical necessity, he describes a rhumb curve on the earth's surface; and this curve is represented by a straight line (and can therefore be at once drawn with a rule) on the "*Mercator's chart.*" Hence this is the projection of main importance in navigation. (3) Where great-circle sailing is practicable and advantageous, a chart on the "*central projection*" exhibits the track as a straight line, and is therefore convenient.

For a short history and description of the charts on which the navigator projects the position and track of his ship, see a paper by the author in *Naval Science*, July, 1872, "Rhumb and Great Circle Charts."

Besides these charts, in which the geographical features are inserted, the navigator uses *wind charts*, *current charts*, *magnetism charts*, *passage charts*. These are all most useful to him when on Mercator's projection.—See under **Winds, Currents, Magnetism, Passages.**

Chronometer (Gk. χρόνος, "time;" μετρεῖν, "to measure").—A watch of superior construction used for purposes where an accurate account of time is required—by the navigator to determine his longitude. Like the common watch, it has for its moving power a mainspring, but the force of this is rendered uniform by a variable lever. The principal characteristic of its construction is the contrivance for compensating for the effects of changes of temperature. A change of temperature, causing expansion and contraction in the different parts of the mechanism, is the chief cause of the irregularity of watches, and a navigator carries his watches through all varieties of climate. The chronometer is therefore furnished with an *expansion balance*, formed by a combination of metals of different expansive qualities (as brass and steel), which effects the compensation required. Another cause which affects the regularity of watches is any violent action to which they may be subject, such as the jerks and vibrations of a ship. Electricity and magnetism are also said slightly to influence them. These sources of irregularity may in a great measure be guarded against by proper treatment of chronometers on board ship. The temperature of the chronometer-room may be regulated by lamps; they may be defended from violent motion, by their cases being lined with cushions of soft wool, and by being preserved in a horizontal position by suspension in gimbals; and care should be taken to wind them up at regular intervals. No chronometer, however, can be made absolutely perfect, so as not to be influenced by disturbing causes; the navigator, therefore, acknowledges the want of perfection, and directs his attention to determine the resulting error, and to detect any variation in the going of his timepiece.

The best English work on Chronometers is "Notes on the Management of Chronometers and Measurement of Meridian Distances," by Admiral Sir Charles Shadwell, K.C.B., F.R.S. Published by J. Potter, 31, Poultry, London.

The articles which follow are arranged, not in an alphabetical, but in a natural, order.

Chronometer, Standard.—The chronometer upon which, of all on board, most dependence can be placed. It is best, however, simply to consider it in the light of that with which, for convenience, the rest are compared, and to which all observations involving time are, in the first instance, referred.

Chronometer, Observation.—Commonly called the "*Deck*" or "*Hack Watch.*" A small portable chronometer (as distinguished from "box chronometers") used for taking the time of observations. It should always be compared immediately before and after an observation with the standard chronometer.

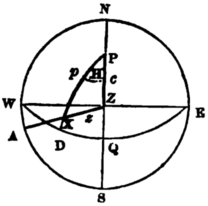
Chronometer, Error of.—"*The Error of Chronometer on Mean Time at any place*" is the difference between the time indicated by the chronometer and the mean time at that place. "*The Error of Chronometer on Mean Time at Greenwich*" is the difference between the time indicated by the chronometer and the mean time at Greenwich. The error is said to be *fast* or *slow* as the chronometer is in advance of or behind the mean time in question. Before sailing, a navigator is supposed to know the error of his chronometer on Greenwich mean time; and it is of vital importance that he should be able constantly to determine this error. The problem is simply how to find the mean time at any place. The difference between this time and the time indicated by the chronometer gives its error on mean time of the place; the Greenwich mean time is deduced by applying the longitude in time to the mean time of place of observer, and hence the error of the chronometer on Greenwich mean time can be found. The following are the methods usually adopted for finding the error of chronometer:—

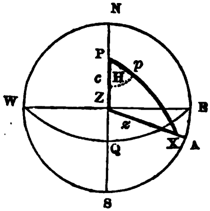
1. *The sidereal clock of an observatory* gives us sidereal time at any instant at the station, from which mean solar time may be deduced with the aid of the Tables of Time Equivalents given in the Nautical Almanac. The institution of *time-balls* renders the clocks of observatories publicly available, and ships while lying in any of our principal ports may always thus obtain the error of their chronometers on Greenwich mean time.

2. With *a portable transit instrument.* The instant when a heavenly

body passes the meridian may be observed by this means. (1) *A star's transit.* The right ascension of a star is the same as the sidereal time at a place at the instant when the star is on the meridian of that place; and from this the mean time may be deduced. (2) *The sun's transit,* When the sun's centre is on the meridian it is apparent noon at the place, from which, by applying the equation of time, the mean time may be deduced.

3. With ***sextant and artificial horizon; observation of a single altitude*** of a heavenly body when not too near the meridian. This altitude ($AX = a$),





with the declination of the body ($DX = \delta$), and the latitude of the place ($QZ = l$) enables us to compute the hour-angle (H) of the body. Let $z = 90 - a$, $p = 90 \pm \delta$, $c = 90 - l$; then in the triangle PZX we have the three sides to determine the angle H, which may be done by one of the formulæ:—

$$(a) \quad \text{Cos}^2 \frac{H}{2} = \frac{\sin S \sin (S - z)}{\sin p \sin c}$$

$$\text{When } S = \frac{z + p + c}{2}$$

$$(b) \quad \sin^2 \frac{H}{2} = \frac{\sin \frac{1}{2} (z + \overline{p \sim c}) \sin \frac{1}{2} (z - \overline{p \sim c})}{\sin p \sin c}$$

$$(c)\quad \text{hav H} = \frac{\sqrt{\text{hav}\,(z + \overline{l \overset{+}{\sim} \delta})\,\text{hav}\,(z - \overline{l \overset{+}{\sim} \delta})}}{\cos\delta\cos l}$$

($l \overset{+}{\sim} \delta$ according as l and δ are of different or same names). Hence,

$$\text{L.hav H.} = \text{L.sec}\,\delta + \text{L.sec}\,l - 20 + \tfrac{1}{2}\,\text{L.hav}\,(z + \overline{l \overset{+}{\sim} \delta})$$
$$+ \tfrac{1}{2}\,\text{L.hav}\,(z - \overline{l \overset{+}{\sim} \delta}).$$

(1) If *a star* is the body observed, the hour-angle, with the R.A. of the star gives sidereal time, from which mean time can be found. (2) If *the sun* is the body observed, the hour-angle gives the apparent time, from which mean time can be deduced.

4. With *sextant and artificial horizon; observation of "equal altitudes."* (1) *A star* observed. The declination of a star is invariable between the two observations of equal altitudes, and therefore the same altitude corresponds to the same hour-angle on each side of the meridian, and the middle point of time between the instants of two equal altitudes is the instant at which the body passes the meridian. Hence sidereal time may be deduced, and mean time be obtained. (2) *Sun* observed. If the sun's declination, like a star's, were invariable, the mean of the observed times of equal altitudes, A.M. and P.M., would be apparent noon. But in the interval the sun sensibly changes its declination, and hence the necessity for a correction, which is called the "equation of equal altitudes." This being applied, the chronometer time at apparent noon is accurately obtained, and hence at mean noon.

Chronometer, Rate of.—The rate of a chronometer is the daily change in its error, or the interval it shows more or less than twenty-four hours in a mean solar day. If the instrument is going too fast, the rate is called *gaining;* if too slow, *losing.* The rate is obtained by determining the error of the chronometer on mean time at the same place on different days by some one of the methods used for that purpose. If the error is found to remain unaltered, there is no rate; if it is observed to change, we know from the amount of that change and the time elapsed how much it gains or loses in twenty-four hours, *i.e.* its rate. If possible, the error should be taken on successive days, at the same hour. A chronometer is best rated at an observatory. Before going to sea it is necessary for the navigator to know, in addition to the error of his chronometer on Greenwich mean time, its rate.

Chronometer, Sea-rate of.—The rate of a chronometer deduced from the change in its error during a sea passage. When a ship leaves a place, and after an interval of not more than a fortnight returns to it again, the error of the chronometer is determined at her departure and on her return. The difference between the two, divided by the interval elapsed, gives the sea-rate, which will in general be found not to be the same as the rate would have been had the ship remained in harbour between the two observations, and it is evidently of more value.

Chronometer Journal.—The book kept for the daily record of the comparisons of the chronometers on board ship. There are several forms in use, but all vessels in H.M. service keep and return the official one approved by the Admiralty; it may be found in the Admiralty Instructions. Besides the "Chronometer Journal," a "Chronometer Sight Book" and "Chronometer Work Book" are most desirable.

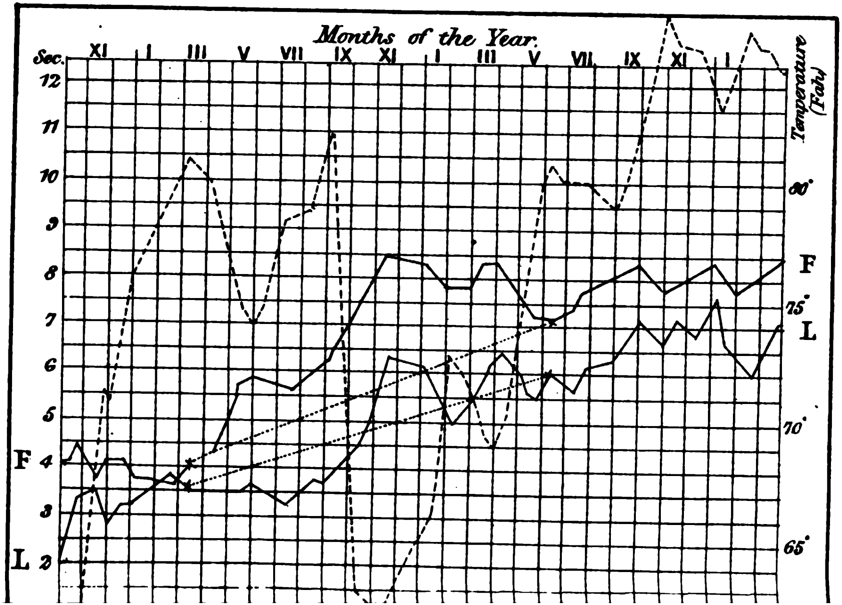
Chronometer Diagrams.—The Chronometer Journal may be embodied in diagrams, though their utility has not been as yet generally acknowledged by English navigators. Their construction has been investigated in France by Mons. E. Mouchez, and by M. Aved de Magnac. Specimens of *Feuilles Mensuelles* and *Feuilles Annuelles* may be found in *Cours de Navigation et d'Hydrographie*, par E. Dubois.

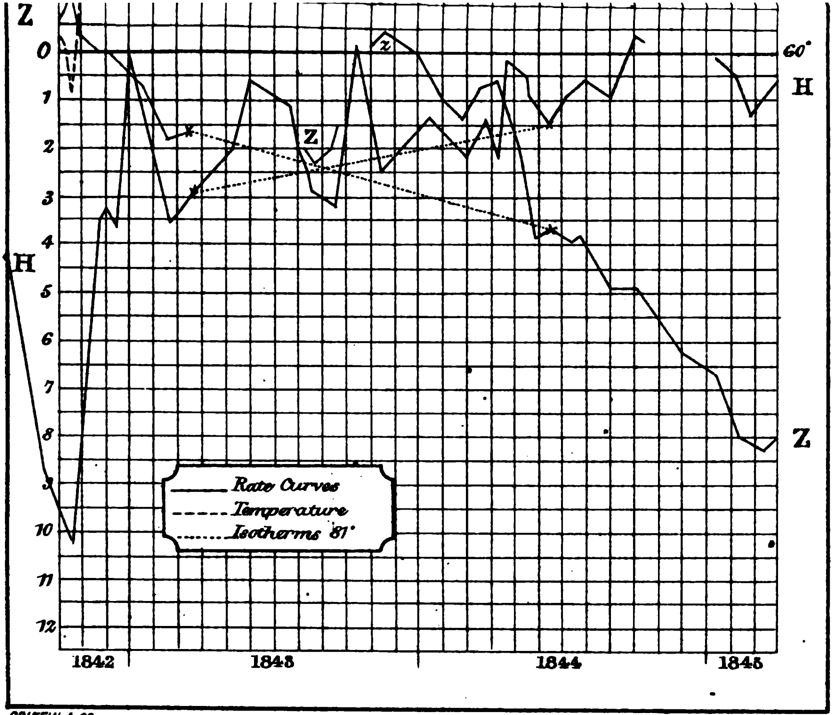
I wrote a short article on "The Chronometer Journal in Diagram" in *The Nautical Magazine*, September, 1866, and then proposed two methods for depicting the comparative or relative rate curves; and I discussed the whole subject in a paper—"Chronometer Diagrams"—in *Naval*

CHRONOMETER DIAGRAM Nº I.

ABSOLUTE RATE CURVES.

H. M. Surveying S. "Fly," Australia.
1842 — 1845.





GRIFFIN & Co PORTSMOUTH.

Science, January, 1875. The substance of these articles is given here as the requisite information for the construction of diagrams is not easily accessible to the majority of navigators.

The curves are of two kinds, absolute rate curves and relative rate curves. Both are projected on a simple form similar to those used for thermometer and barometer diagrams. On a sheet of cross-ruled paper the abscissæ will represent the times and the ordinates the rates. The region above the zero line is considered positive, and that below negative. The examples given below are all taken from actual Chronometer Journals.

I. Absolute Rate Curves.

When the absolute rate of a chronometer is deduced from time to time by a comparison of the errors determined from observations, there is no difficulty in marking off the errors corresponding to different dates. By joining the points so obtained, the fluctuations in the rate will be graphically represented by a curve. On the same diagram may be drawn the absolute rate curves of all the chronometers on board; and if this be kept marked up throughout a ship's commission, it will exhibit a very palpable picture of the idiosyncrasy of each watch. The two circumstances which chiefly affect chronometers over a long period are, lapse of time, and changes of temperature. Many chronometers exhibit a very regular tendency to a gradual acceleration of rate, as time advances, since they were last adjusted; and there is generally a tendency to an increase of gaining rate upon a decrease of temperature.

Diagram No. 1 gives a portion of the absolute rate curves of four of the chronometers (Z, F, H, L,) of H.M.S. "Fly," employed in surveying the coast of Australia, in 1842–1846. It is constructed from the table given in Shadwell's "Notes on the Management of Chronometers," pp. 224, 225. This diagram is on a much smaller scale than should be practically used for so long a period, a whole month being included between the vertical lines. The effects of the lapse of time may be isolated by drawing isotherm lines. In the figure the isotherms of 81° are drawn, covering a period of fifteen months; and they show that the rates of watches F, H, and L were accelerated by the lapse of time, and that of Z retarded. A sudden fall of temperature, within the period of two months, from 82° to 62° has a marked effect, as, during this interval, the gaining rates were increased from 2^s to 3^s for all the four chronometers.

II. Relative Rate Curves.

There are two methods of drawing the comparative or relative rate curves. In both, the vertical columns represent successive days, and the horizontal columns, differences of rates of 1^s or $\cdot 5^s$, as found necessary. In the first method, no standard chronometer is acknowledged, the judgment being left unbiassed, and every chronometer being valued according to its behaviour; in the second method, an imaginary mean chronometer is regarded as the standard, and to the irregularities of this all the chronometers contribute. The latter method was suggested to me by my college friend, the late Mr. Hugh Godfray.

(1) *First Method.*

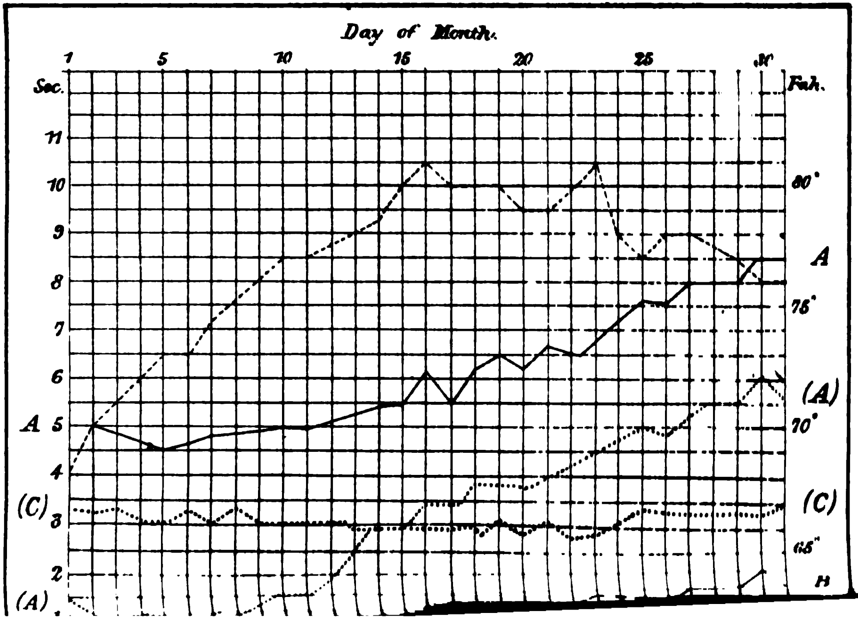
A dark horizontal line is taken as the zero line, from whence the ordinates denoting the daily differences of the chronometers, taken two and two together, are measured, the region above being considered positive, and that below negative. On any given day, the sum of the ordinates is equal to zero, this check always holding good. Each curve, then, depicts the fluctuation in the *combined* rates of the two watches compared, *i.e.* the daily difference of the differences of the pairs A and B, B and C, C and A. It is probable that the irregularities in the curve which exhibits the comparison of A and B will be caused chiefly by the fluctuations in the rate of one of them, A *or* B, and similarly for the others. The more

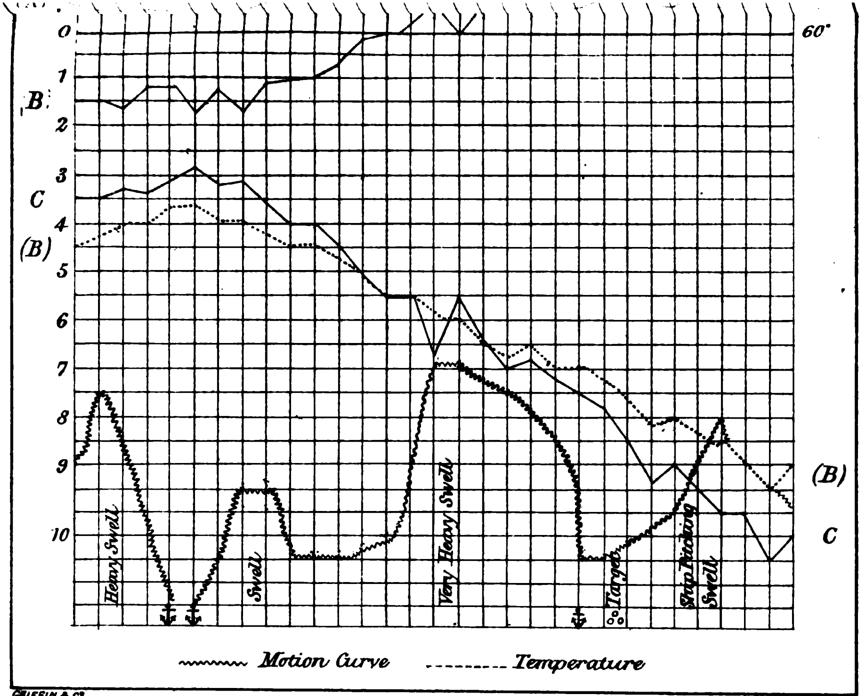
CHRONOMETER DIAGRAM Nº 2.

RELATIVE RATE CURVES.

H. M. S. "Flying Fish"; England to Cape of Good Hope.

August, 1874.





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irregular a curve, then, the greater the probability that one of the watches involved is going badly. Hence, if we name each curve by the watch *not* involved, writing the distinguishing letter in brackets, as (A), that curve may then be taken, by its inverse form, to indicate the degree of reliance to be placed on the watch; in other words, the less irregular the curve which is called by the name of the watch not involved, the less valuable will be the indications of that watch. With a view to diagrams on this plan, the most convenient form of the chronometer journal is as follows:—

Date.	A	A—B	Daily Diff.	B	B—C	Daily Diff.	C	C—A	Daily Diff.
	h. m. s.	*m. s.*	*s.*	*h. m. s.*	*m. s.*	*s.*	*h. m. s.*	*m. s.*	*s.*
Aug. 1	10 5 0	10 29·5	6·5	9 54 30·5	0 12	2·0	9 54 18·5	10 41·5	8·5
" 2	9 47 0	10 36	6·5	9 36 24	0 14	1·5	9 36 10	10 50	8
" 3	10 13 30	10 42·5	6·0	10 2 47·5	0 15·5	2·0	10 2 32	10 58	8
" 4	9 54 0	10 48·5		9 43 11·5	0 17·5		9 42 54	11 6	
etc.		etc.			etc.			etc.	

This is the commencement of the journal represented in diagram No. 2. One division of the ordinates is equal to 1″. In this diagram we notice that the curve (C) has very small fluctuation from the horizontal, while (A) and (B), before a third of the month is over, begin to depart from regularity, and by the end of the month are very divergent. Now, as the watch C is involved in each of these curves (A) and (B), we, with great probability, put that watch down as the offender which is indicated also, at once, by the curve (C) being very regular. Diagrams formed on this plan do not, however, seem to be so well suited for exhibiting, side by side, the curves of absolute rates with those of relative rates, nor for connecting the fluctuations of the rate curves with the disturbing influences. And one feature, which renders diagrams so valuable, we must always bear in mind, is the facility with which the disturbing influences may be depicted, thus furnishing means of assigning each irregularity in the rate curves to its proper cause. When there are three watches on board, this method has the advantage of simplicity, but with a larger number, the work of getting out the differences renders it inconvenient.

In diagram No. 2, the curves on this from (A), (B), (C) are given for the three chronometers of H.M.S. "Flying Fish" during the month of August, 1874. The curves drawn on the second method, which follows, are given on the same sheet. The commencement of the chronometer journal is also inserted. We are indebted for this example to Mr. R. W. Middleton, navigating officer.

(2) *Second Method.*

The axis of x represents the going of an imaginary mean watch, and the daily differences of the differences between this mean watch and the chronometer give the ordinates of the rate curves of the different chronometers. The chronometer journal may be conveniently tabulated as follows:—We take the same example, and place the curves A, B, C, on the same diagram; but here each division on the axis of y represents half a second instead of one second as before.

1874.	August 1st.	2nd.	3rd.	4th.	etc.
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	
A	10 5 0	9 47 0	10 13 30	9 54 0	
B	9 54 30·5	9 36 24	10 2 47·5	9 43 11·5	
C	9 54 18·5	9 36 10	10 2 32	9 42 54	
$\frac{1}{3}$	29 53 49	28 59 34	30 18 49·5	29 20 5·5	
M	9 57 56·3	9 39 51·3	10 6 16·5	9 46 41·8	
a	+ 7 3·7	+ 7 8·7	+ 7 13·5	+ 7 18·2	
δa		+ 5	+ 4·8	+ 4·7	
b	− 3 25·8	− 3 27·3	− 3 29	− 3 30·3	
b		− 1·5	− 1·7	− 1·3	
c	− 3 37·8	− 3 41·3	− 3 44·5	− 3 47·8	
δc		− 3·5	− 3·2	− 3·3	

Where $a = A - M$, $b = B - M$, $c = C - M$, and δa, δb, δc are the daily variations of these differences. These latter are the quantities embodied in the curves. Checks in the calculation are afforded by the conditions $a + b + c = 0$, and $\delta a + \delta b + \delta c = 0$.

Diagram No. 3 gives the rate curves of the three chronometers of H.M.S. "Hotspur," Mediterranean, for the month of December, 1876, Mr. F. K. Taylor, navigating officer. During the whole of the month, with the exception of four days, the ship was at anchor, and the fluctuations will probably be all due to changes of temperature. In the example, diagram No. 2, motion is a considerable factor.

Chronometric Difference.—A term proposed instead of **Meridian Distance,** which see.

Circles of the Sphere.—If we conceive the sphere to be generated by the revolution of a circle about one of its diameters as axis, then the "circles of the sphere" may be defined as those circles which are described on its surface by the extremities of such chords of the generating circle as are at right angles to the axis. The two extremities of the axis are considered to be the "poles" of each circle of such a system. Any diameter of the generating circle may be made the axis. Or, we may regard the circles of the sphere as originating from the section of its surface by a plane.

Circles, Great.—Great Circles of the Sphere are those whose planes pass through the centre of the sphere, and which are therefore equally distant from both their poles, dividing the sphere into two equal parts. Distinguished from *Small* or *Lesser Circles.*

Circles, Small, or **Lesser.**—Small or Lesser Circles of the Sphere are those whose planes do not pass through the centre of the sphere, and which are therefore unequally distant from their two poles, dividing the sphere into two unequal parts. Distinguished from *Great Circles.*

Circles, Primary and Secondary.—The position of all points on the sphere may be defined by a system of co-ordinates, the axes of which are a definite great circle and a system of great circles perpendicular to it; the former is called the *Primary Great Circle*, the latter its *Secondary Great Circles.*—See **Co-ordinates for the Surface of a Sphere.**

Circles of Altitude, Declination, Latitude.—In the different systems of co-ordinates for the surface of the celestial sphere, it is the common practice to regard the secondary great circles as ordinate circles to the primitive, and they are hence named after that one of the co-ordinates which is measured *upon* them. Thus, the great circles which are ordinate circles to the horizon are called *Circles of Altitude*, because altitudes are measured upon them; the great circles which are ordinate circles to the equinoctial are called *Circles of Declination*, because declinations are measured upon them; and the great circles which are ordinate circles to the ecliptic are called *Circles of Latitude*, because latitudes are measured upon them. Under a different system of nomenclature these are severally called *Circles of Azimuth*, *Circles of Right Ascension*, and *Circles of Longitude.*—See **Co-ordinates for the Surface of a Sphere.**

Circles of Azimuth, Right Ascension, Longitude.—In the different systems of co-ordinates for the surface of the celestial sphere, some writers allow the conception of polar co-ordinates to predominate, and thus regard the secondary great circles as sweeping out angles at the pole; they therefore name them after that one of the co-ordinates which is marked out *by* them. Thus the great circles passing through the poles of the horizon are called *Circles of Azimuth*, because they each mark out all points which have the same azimuth; the great circles passing through the poles of the equinoctial are called *Circles of Right Ascension*, because they each mark out all points which have the same right ascension; and the great circles passing through the poles of the ecliptic are called

Circles of Longitude, because they each mark out all points which have the same longitude. Under a different system of nomenclature these are severally called *Circles of Altitude*, *Circles of Declination*, *Circles of Latitude*.—See **Co-ordinates for the Surface of a Sphere.**

Circles, Vertical—or simply "*Verticals*."—Great circles of the celestial sphere, passing through the "vertex" of the heavens; they are perpendicular to the horizon. Also called "*Circles of Altitude*," and "*Circles of Azimuth*."

Circles, Hour.—Great circles of the celestial sphere perpendicular to the equinoctial, and therefore passing through the poles of the heavens. They severally mark out all points which have the same *hour-angle*.—See **Co-ordinates for the Surface of a Sphere.**

Circle, Diurnal (L. *diurnus*, "pertaining to a day, from *dies*, "a day").—The diurnal circle of a heavenly body is the circle it describes by the apparent daily revolution of the celestial concave. If the declination remains unchanged, the diurnal circle is coincident with the parallel of declination passing through the body. Only when the body is in the equinoctial is it a great circle. At the equinoxes the sun's diurnal circle is nearly coincident with the equinoctial; at the summer and winter solstices, its diurnal circles in the heavens correspond nearly to the tropics of Cancer and Capricorn on the surface of the earth.

Circle of Perpetual Apparition.—That parallel of declination beyond which all the diurnal circles lie wholly above the horizon. Its polar distance is equal to the latitude of the observer's station.

Circle of Perpetual Occultation.—That parallel of declination beyond which all the diurnal circles lie wholly below the horizon. It is at the same distance from the depressed pole as the *Circle of Perpetual Apparition* is from the elevated pole.

Circle of Illumination.—Approximately one-half of the earth's surface is always illuminated by the sun, while the opposite hemisphere is in the shade. The great circle which at any instant is the boundary between the illuminated and darkened hemispheres is called the Circle of Illumination.—See **Illumination.**

Circles, Polar—The **Arctic** and **Antarctic** Circles.—Small circles of the terrestrial sphere, parallel to the equator, at the same distance from the north and south poles as the tropics are from the equator. This distance is about 23° 28′; these circles are therefore parallels of latitude of about 66° 32′ N. and S.; "about," because their position is subject to slight periodical change.

Circle of Curvature.—The circle whose curvature is the same as that of the curve under consideration, at any given point.—See **Curvature.**

Circle, Troughton's Reflecting.—A very elegant instrument, which is the same in principle as the sextant, and applied to the same uses. The accompanying figures will illustrate our brief notice of its peculiarities. The essential requisite in the construction of *all* reflecting astronomical instruments is, that lines from the place of the eye and from the movable reflector at the centre of the arc to the fixed reflector, should make equal angles therewith. In the reflecting circle, the graduated limb consists of

Fig. 1.

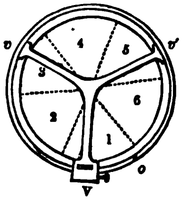
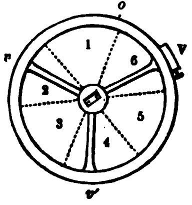


Fig. 2.

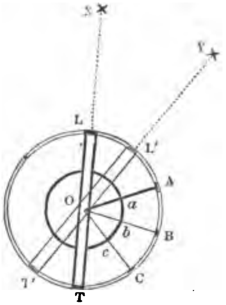


a complete circle, which is equivalent to six sextants, the adjuncts of the instrument and manner of observing bringing each of these sextants into play. There are three verniers (V, *v*, *v*′), the triple bar which carries them being of course connected and moving with the index glass. One of these verniers (V) is furnished with the clamp and tangent-screw for regulating the contacts, and when the reflectors are parallel this index stands at or near 0. A complete observation with this instrument requires that the angle shall be taken *directly* and *reversely*. The direct observation (fig. 1) of the angle is made, as with the sextant, by pushing the index forward along the limb. The degree, minute, and second is now read off by that vernier to which the tangent-screw is attached (V); also the minutes and seconds shown by the other two verniers (*v*, *v*′). The angle is thus measured on three different sextants. The reverse observation (fig. 2) of the angle is made by moving the index back along the limb to about the same distance from the 0 as it was before moved forward, then reversing the instrument by turning it half a revolution round the line of vision, and finally making a perfect contact of the images with the aid of the tangent-screw. The central reflector will now be turned from its initial position, parallel to the fixed reflector, to the same extent, but in the opposite direction, to what it was in the direct observation. The three verniers are then read off as before, and thus the angle is measured on the three remaining sextants of the circle.

The mean of all six readings-off is the true apparent angle, corresponding to the mean of the two times at which the direct and reverse observations were made.

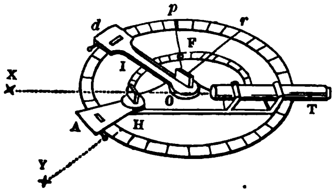
The advantages of this instrument, as compared with the sextant, are these:—By observing directly and reversely, all observations for finding the index-error are rendered unnecessary; for if the commencement of divisions be erroneous one way when the index is pushed forwards, it will be so far wrong the other when the index is pushed backward, diminishing or increasing the angle read off in the one case as much as it increases or diminishes it in the other. Again, the errors resulting from want of parallelism in the surfaces of the dark glasses are eliminated. When the instrument is reversed the direction of their inclination is changed, and consequently the effect on the angle measured will be of a contrary kind—*i.e.* if it increased the angle before, it will now diminish it, and as much, and *vice versâ.* The mean of the two sets of readings-off will therefore be the true apparent angle, independent of index-error and error for imperfect shades. Thus, also, the errors of the horizon-glass are entirely corrected, and those of the index-glass very nearly. By having the three verniers to read off from different parts of the arc of the circle, any error resulting from imperfect centring is altogether corrected. If a single bar carried the index, and revolved upon an axis not exactly at the centre of the graduated circle, the angle indicated would be too large or too small; but if it is too large at one part of the circle, it will be too small at the opposite. Such errors are, therefore, eliminated by having the triple index-bar. By taking the mean of the two sets of three readings each, errors arising from want of exactness in the graduation of the limb, or from the effects of warping, or any slight errors in reading off which do not compensate each other, are reduced to one-sixth of their simple value. The circle also has an advantage over the sextant in furnishing the means of measuring a larger angle. The adjustments of the two instruments are of the same nature.—See **Sextant.**

Circle, Repeating.—A circle for measuring angular distances, con structed upon a beautiful principle invented by Borda. As absolute perfection in graduating an arc cannot be attained, errors resulting therefrom are by this means indefinitely diminished, at least in theory. A brief description of "the principle of repetition" will explain the distinguishing characteristic of the instrument. O is the common axis of two circles ABC and *abc*. The larger circle ABC has its limb graduated, and is placed in the plane passing through the two objects whose angular distance is to be measured; let these (supposed fixed) be X and Y. The smaller circle *abc* carries the telescope TL, which is fixed to it, revolving on the axis O. A bar O*a*A carries the vernier which reads off the graduations of ABC; it is furnished with two clamps, by which it can be alternately attached to either circle and detached from the other. Let the telescope be directed to X; then read off. Clamp the index-arm OA to *abc*, unclamping it from ABC, and carry the telescope round to the other object Y. The index-arm, being clamped to *abc*, is thus carried over an arc AB, which measures the angular distance (XOY) of X and Y. Let it be clamped to ABC. If we now read off, the difference of the two readings obtained would give the angular distance required, but affected by the errors arising from imperfect graduation, which it is the express object of the repeating circle practically to get rid of. Instead, then, of reading off the arc AB, the index-arm, being clamped to ABC, is unclamped from *abc*, and then the telescope is moved back to the object X, leaving the index at B. The index-arm is now clamped to *abc*, and unclamped from ABC, and the telescope again directed to the second object Y, carrying forward the index-arm to C. The index will now have *repeated* the arc AB, and the whole, AC, if read off, would be twice the angular distance of X and Y. The process may be repeated any number of times (for example, ten), and the final arc read off will be that number of times the angle XOY. This reading will be affected by an error due to imperfection in graduation depending on two readings-off alone, those corresponding to the initial and final position of the index; and in dividing the whole arc by the number of times AB is repeated (*e.g.* ten), this constant error of graduation is divided to the same extent. Thus, in the example, the measurement of XOY is affected with only



one-tenth of the constant error of graduation. One great convenience of this instrument is that, in effect, the mean of a number of observations of an angle is obtained without the tediousness of multiplied readings-off. Again, "errors of observation" virtually disappear from the result, for these, when numerous, tend to balance and destroy each other. Some unknown obstacle, however, prevents any practical realization of the abstract advantage offered by the principle of repetition.

Circle, Borda's Repeating Reflecting.—In this instrument the measure of an angular distance is taken by reflection, as in the simple reflecting circle; also the "cross-observation," as it is called, is the same in principle as the pair of observations taken directly and reversely. The principle of repetition is made available by using the index-glass and horizon-glass alternately as the *fixed* mirror. The index-glass (at centre O, as in sextant) carries the index-arm and vernier I. The horizon-glass H, and the telescope T, revolve together round the centre with the vernier A. To the bar which carries these is attached also an inner circular arc F, divided to degrees, called the "finder," as it enables us to set the mirrors to any given inclination, and thus at once to bring two objects into contact roughly. The divisions of the finder are reckoned in both directions from the 0; and when the vernier I is set to this 0, the index-glass and horizon-glass are parallel. The telescope bar can be clamped at pleasure to the circle; so also the index-bar may be clamped either to the circle or to the finder. Let the angular distance between X and Y be required. When the index-bar stands at *d*, the angle *pOd* measures this distance. If the instrument be "reversed," and a contact then made, the index-bar will have moved



through the position of parallelism O*p* to O*r*, the angle *p*O*r* being equal to *p*O*d*, and *d*O*r* equals twice the angular distance of X and Y. Let the instrument be now restored to its original position. Leaving the index-bar clamped to the circle (being unclamped from the finder), move the horizon-bar through the same angle (*d*O*r*) and in the same direction as the index-bar travelled; a rough contact of the two objects will be thus again made, which contact is perfected by the tangent-screw on the horizon-vernier. Everything is now exactly as it was at starting, except that the two verniers are transferred to other points of the circle, distant from their original positions by twice the angle measured. The operation may thence be repeated any number of times.

The theoretical advantages of this instrument in eliminating or diminishing errors will be understood from the two preceding articles.

Circummeridian (L. *circum*, "about").—About or near the meridian. *Circummeridian altitudes* are a set of altitudes of a body taken when it is in the vicinity of the meridian.—See under **Altitude.**

Cirro-cumulus.—One of the intermediate modifications of cloud.—See **Cloud.**

Cirro-stratus.—One of the intermediate modifications of cloud.—See **Cloud.**

Cirrus (L. "a lock of curled hair").—The "Curl-cloud;" one of the primary modifications of cloud.—See **Cloud.**

Civil (L. *civilis*, "relating to the community of citizens").—The civil *time*, *year*, *day*, is that reckoning which is adopted for the social purposes of life.—See **Calendar.**

"Clearing the Distance."—In finding the longitude by a "lunar distance," the operation of deducing the true from the apparent distance is technically called "clearing the distance." For the methods of doing this see under **Longitude, Lunar Distances.**

Clinometer, Ship.—An instrument for measuring the angle through which a ship heels.

1. The simplest form is a *Pendulum* attached to an athwartship bulkhead, with an accompanying arc to indicate its departure from the vertical.
2. A better and equally simple contrivance is a pair of *Rolling Battens;* these are graduated perpendiculars placed at the extremities of the bridge, whence the horizon is visible.
3. *Nolloth's Ship-Clinometer* is a simple instrument formed on the principle of a carpenter's rule; applicable in a heavy sea, when the pendulum is useless.
4. *Short's Patent Ship-Clinometer* is an instrument consisting of a tabular arc of glass, iron, and vulcanite, partly filled with mercury. The top of the column of mercury, visible in the glass portion, rises or falls as the ship rolls, and indicates, against a scale boldly graduated to 1°, the real angle of the roll of the ship. An electric apparatus is added, by which a signal from a bell is given when the ship reaches a dangerous roll,

[See "Journal" of the Royal United Service Institution, vol. xxvi., No. cxiv., 1882. Also vol. xv., No. lxii., 1871.]

Clocks and Watches.—Navigation is vitally concerned with the machines by which time is measured. Every scientific navigator should understand generally the principle and construction of the astronomical clock in the shore observatory, and of the chronometer on board his ship.

There are three essential parts in all such instruments:—(1) the *Moving Power*, (2) the *Converting Mechanism*, (3) the *Regulating Agency*. (1) The moving power in astronomical clocks consists of a heavy weight, which descends by the force of *gravity*, the cord which suspends it passing over and giving a rotatory motion to a horizontal axle. The moving power in chronometers consists of a spring, which is coiled up within a barrel, and unwinds itself by the force of its own *elasticity.* (2) The converting mechanism in both clocks and watches is formed of *a series of wheels and pinions* (small wheels furnished with what are called leaves, working in the cogs of larger opposing wheels). By this train a rotatory motion may be obtained, having any required ratio to that of the primary axle. (3) The regulating agency in astronomical clocks consists of a *pendulum,* the oscillations of pendulums of uniform length being isochronous, or performed in equal times. The regulator in chronometers consists of a *balance,* making isochronous vibrations.

The contrivances by which these essential parts are articulated together constitute an important element in the construction of timekeepers. The energy of the moving power has to be periodically renewed by "winding up," which raises the weight or coils the spring. By the manner in which the moving power is connected with the commencement of the wheel-work this process can be effected without arresting the motion of the other parts of the machine. In watches a *Maintaining Power,* consisting of a second spring, has to be introduced at this point. And the other end of the converting mechanism is the regulating agency, and these two are combined by what is called the *Escapement.* Unless restrained, the descending weight of the clock would acquire an accelerated motion and rapidly run down, and similarly, the spring of the watch would at once uncoil itself. The escapement provides the necessary checking influence, by bringing the alternating action of an oscillating body (the pendulum, or balance) and the rotatory motion of the wheel-work to act and react upon each other. The pendulum acts, not only as the regulating agency, but contributes to the moving power by the action of gravity; the balance derives its motion entirely by its being transmitted to it from the spring. Both pendulums and balances are constructed so as automatically to compensate the disturbing effects of changes of temperature. A uniform motion is thus sustained and communicated by the wheel-work to the hands which indicate, on the dial, the lapse of time.

Clock, Astronomical.—A pendulum clock, of very superior construction, and specially adapted for astronomical observations. It is an indispensable piece of furniture in every observatory. [A short and clear description of observatory instruments is given in "A Treatise on Astronomy," by Hugh Godfray (Macmillan and Co.).] The chief cause of irregularity in the going of clocks is the expansion and contraction of the pendulum from changes of temperature. Compensating pendulums (such as the gridiron of Harrison, or mercurial of Graham), as now constructed, secure an isochronous motion—*i.e.* a perfect equality in the duration of the oscillations. Another important point in the mechanism is the "escapement," which sustains the motion of the pendulum and records its vibrations; and here also great perfection has been attained. Huyghens first adopted the pendulum, and to him also is due a simple means of winding up the clock without interfering with its regular and uniform progress. In the astronomical clock the second's tick is very distinct, so that while the eye of the observer is engaged at the telescope, the ear may note the time. It is adjusted to show *sidereal time*, indicating $0^h\ 0^m\ 0^s$ when the first point of Aries is on the meridian of the station, and going twenty-four hours between two successive transits of that point. The astronomer sets and regulates his sidereal clock by observing with the transit instrument the meridian passages of the more conspicuous and well-known stars. Each of these holds in the heavens a known place with respect to the first point of Aries, and by noting the times of their passage in succession, he knows when the first point of Aries passed. At that moment his clock ought to have indicated $0^h\ 0^m\ 0^s$; if it did not, he knows and can correct its *error*. Again, by the agreement or disagreement of the errors given by each star, he can ascertain whether his clock is correctly regulated to go twenty-four hours in one diurnal period; and if not, he can ascertain and allow for its *rate*. Hence, by applying the error at a definite date, and the accumulation of the rate since, to the indication of the clock, the exact sidereal time proper to the locality of the station can always be obtained. The astronomical clock is of the greatest importance directly to the navigator, as furnishing a ready means of obtaining, by comparison, the error and rate of his chronometer.

Clock, Mean Solar.—A clock which indicates *mean solar* or *civil time*, and is therefore adjusted to go twenty-four hours during the average length of the day, or one complete diurnal revolution of the mean sun in the heavens. The ratio which the duration of the mean solar day bears to that of the sidereal day is 1·00273791 to 1; hence it will be found that the twenty-four hours of the mean solar clock corresponds to $24^h\ 3^m\ 56{\cdot}55^s$ of the sidereal clock.—See **Day.**

Clock, Sidereal.—A clock which indicates *sidereal* time.—See **Clock, Astronomical.**

Cloud.—A mass of visible vapour floating in the atmosphere. The classification of clouds and nomenclature introduced by Mr. Luke Howard is the system universally adopted, though later meteorologists have suggested modifications and amplifications. Howard defines and describes the three *simple* and distinct modifications of cloud, which he names "Cirrus" (ci.), "Cumulus" (cu.), and "Stratus" (s.); then two *intermediate* modifications, the "Cirro-cumulus" (ci-cu.), and "Cirro-stratus" (ci-s.); with two *compound* modifications, the "Cumulo-stratus" (cu-s.), and the "Cumulo-cirro-stratus," or "Nimbus" (n.) We have placed in parentheses the notation adopted to register each variety.

Simple Modifications.

1. *Cirrus* (L. "a lock of curled hair," from Gk. *κέρας*, "a horn").—"Curl-cloud." Clouds of a fibrous structure. Of all the modifications, they have the least density of aggregation, the greatest elevation, and most variety of extent and direction. They are the earliest to appear

after serene weather, as a few white threads pencilled on the sky. These are reinforced by parallel flexuous or diverging streaks and branches, the upward direction of the tufts indicating condensation preceding rain, their downward direction, evaporation and fine weather. Among seamen the cirri are known as "mare's tails," and are regarded as the precursor of windy weather. From their great elevation, the particles are probably frozen, and therefore crystalline; and hence, from reflections and refractions, the appearance of halos and similar phenomena, which are only observed in the cirrus and its derivative forms, especially in the cirrostratus. The halo commonly prognosticates foul weather.

2. *Cumulus* (L. "a heap," from Gk. *κῦμα*, "anything swollen.")—"Heap-cloud." Clouds of a hilly structure. The lower surface is horizontal, the upper consists of conical or hemispherical heaps. Of all the modifications they are the densest, and are generally found in the lower regions of the atmosphere. The cumulus of fine weather has a moderate elevation and extent, and a well-defined rounded surface. Previous to rain it increases more rapidly, appears at a lower level, and with its surface full of loose fleeces and protuberances.

3. *Stratus* (L. "laid flat").—"Flat-cloud." Clouds consisting of an extended, continuous, horizontal sheet, increasing from below. Of the three primary modifications, the stratus is intermediate in density; in position it is the lowest of clouds, its inferior surface generally resting on the earth or water. As the cumulus belongs to the day, so the stratus is the cloud of night. It is dissipated by the return of the sun and morning breeze, when fair and serene weather is ushered in.

Intermediate Modifications.

The cirrus, after continuing for some time stationary or increasing, usually passes, while at the same time it descends to a lower position in the atmosphere, into one of the two following forms:—

1. *Cirro-cumulus.*—Small, roundish, well-defined masses, in close hori-

zontal arrangement or contact, formed by the fibres of the cirrus collapsing, as it were. This beautiful aspect of the sky is frequent in summer. It is the "mackerel-back sky" of warm and dry weather.

2. *Cirro-stratus.*—Horizontally or slightly inclined masses, resulting from the subsidence, as it were, of the fibres of the cirrus. This cloud presents generally the character of the stratus in its main body, of the cirrus in its margin. When seen from a distance, it frequently gives the idea of shoals of fish. It precedes wind and rain, and is almost always seen in the intervals of storms.

Combined Modifications.

1. *Cumulo-stratus.*—The modification of the cumulus, when the columns of rising vapour which go to form it arrive in an upper region, not sufficiently dry to round off its summits by rapid evaporation, allowing them to spread horizontally, and form flat-topped mushroom-shaped masses. Its tendency is to spread, overcast the sky, and settle down into the nimbus.

2. *Cumulo-cirro-stratus* or *Nimbus* (L. the rain-cloud).—A cloud or system of clouds from which rain is falling. It consists of a horizontal sheet, above which the cirrus spreads, while the cumulus enters it laterally and from beneath.

In Admiral Fitzroy's system there are four primary classes of clouds:—1. Cirrus; 2. Stratus; 3. Nimbus; 4. Cumulus. He adopts the principle of combining these words to describe the intermediate modifications, and renders the terms more explanatory of the precise kind of cloud by the use of the augmentative termination *onus* and the diminutive *itus*—*e.g.* cirronus, cirritus, cirrono-stratus, cirrito-stratus, etc.

Co-.—A prefix, being an abbreviation of *Complement.* Thus we have co-altitude, co-declination, co-latitude, co-sine, co-tangent, co-secant.—See **Complement.**

Co-altitude.—The *complement* of the altitude, called also the "*Zenith* *distance.*" $z = 90° - a$. When the body is below the horizon, a is negative, and the co-altitude exceeds 90°.

Co-declination.—The *complement* of the declination, called also the "*Polar distance.*" $p = 90° - \delta$; δ being considered negative when the declination is of a different name from the elevated pole.

Co-latitude.—The *complement* of the latitude. $c = 90° - l$. In very many of the problems of celo-navigation a spherical triangle has to be solved, whose sides are respectively equal to p the polar distance of the heavenly body observed, z its zenith distance, and c the co-latitude of the observer. It must, however, never be forgotten that this being a triangle of the celestial concave, c in this case is actually the *polar distance of the observer's zenith.* The co-latitude of the observer is the corresponding arc of the terrestrial sphere.

Coefficients.—In algebra, the factors whose product constitutes a term are called coefficients of each other. But in expressions whose terms involve constant as well as variable factors, the word *coefficient* is usually restricted to the former, while the latter are distinguished as *facients.* In formulæ embodying physical properties, these coefficients are determined by experiment. The coefficient of friction for any substance is a familiar instance. There is another example familiar to the navigator. The magnetic condition of each individual iron ship is expressed by an algebraical formula, the terms of which involve the coefficients A, B, C, D, E; these represent the components of the constituent parts of the ship's magnetism, and are determined by experiment.

Collimation, Axis or Line of (L. *collimare*, form of *collinĕre*, "to level in a right line;" from *con*, "together," and *linea*, "a line").—The optical axis of the telescope, or the line joining the centre and focus of the object-glass. One of the adjustments of the sextant and similar instruments is that the axis of collimation be parallel to the plane of the arc.

Columba (L. "The Dove").—A constellation next to, and to the S.W. of Canis Major. *α Columbæ* may be found by producing the line joining Procyon and Sirius to about the same distance. Mag. 2; 1882, R.A. $5^h\ 35^m$, Dec. $-34^\circ\ 8'$.

Colūres (Gr. *κόλουρος*, "cutting the tail;" from *κολούειν*, "to cut," and *οὐρὰ*, "the tail"). A term originally applied to any great circle passing through the poles of the heavens. It is derived, by some, from the fact that one part of each of these circles appears always "cut off" by the horizon. A more probable explanation of the word seems to be "cutting the tail" of the northern constellation—*i.e.* passing through the pole star. This star is situated in the tail of the Lesser Bear, a group which appears to have been more anciently figured as a dog; hence the pole star is called the Cynosure (*κυνόσουρα*, "The Dog's Tail," *κύων*, *κόνὸs*, "a dog," and *οὐρὰ*, "the tail"). The word colures has more lately become restricted to the two circles of the system which pass through the four cardinal points of the ecliptic—the equinoctial and solstitial points—the former being called the *Equinoctial Colure*, and the latter the *Solstitial Colure*. The equinoctial colure may be regarded as the initial position of the hour-circle [**Co-ordinates for the Surface of a Sphere**]; the solstitial colure passes through the poles of the ecliptic as well as those of the equinoctial. Even in the modern restricted sense this term is now but little used.

Commensurable (L. *commensus*, "the size of a thing in proportion to another"). Quantities are said to be commensurable when they have a common measure; thus a quarter of an inch, an inch, and a foot, are commensurable. Opposed to **Incommensurable**.

Compass.—The compass is simply an instrument which utilizes the directive power of the magnet; its forms are various, according to the uses it is intended to serve. Its applicability for the purposes of navigation seems to have been recognized in Eastern Asia long before seamen in Europe knew its value. It was adopted in the Mediterranean about the thirteenth century. The compass fitted for use on board ship is called "*The Mariner's Compass;*" and, according to the purposes it is specially adapted for, it is named **The Steering Compass, The Standard Compass,** and **The Azimuth Compass.**

Compass, Steering, or Binnacle.—The "needle" or magnetized bar of steel, or a system of such bars, is attached to the under side of the circular card which represents the horizon, and which is graduated with the rhumbs of the horizon or points of the compass, the north end or "pole" of the needle being fixed under the north point of the card. This (needle and card) is then balanced on a fine point which rises from the bottom of a brass bowl, and protected with a covering of glass. The bowl, properly weighted, is hung in "gimbals," so as to retain a horizontal position during the rolling and pitching of the ship; on the inside of it is a mark called "Lubber's Point," and when the steering compass is properly placed in its position (the ship being upright), a line passing through the pivot and this point is fore-and-aft, or parallel to the keel of the ship. The "binnacle," adapted for protection, and furnished with suitable lamps, receives the whole. The binnacle in some compasses is also furnished with a system of compensators or "correctors" for reducing the deviations. Such instruments are those patented by Sir William Thomson and by Lieutenant Peichl, of the Imperial Austrian Navy. Ships have one or two permanently fixed binnacle compasses. In steering the ship, the object of the helmsman is to keep the keel in the direction of the course prescribed to him; to this end, as the compass card "travels" with the needle, that point, marked on the card, should be kept coincident with the lubber's point on the bowl. This, however, is only the general principle of steering. The binnacle compass is to be regarded solely as a guide to the helmsman, who has his directions given to him by the officer of the watch. The officer has constantly to attend to the indications of the standard compass, which he translates into the corresponding directions for the helmsman at the steering compass.

Compass, Standard.—(I.) That instrument on board ship which is recognized as the authority to which the indications of the other compasses are referred. Its position is carefully selected with a view to its being as free as possible from the disturbing influences of the ship's magnetism; it is adjusted and compensated, and the deviations of which are ascertained and recorded in a Table of Deviations; and the courses entered in the log are those which it would indicate.

(II.) In a naval service, by the Standard Compass is also understood the officially authorized compass, and we may refer to those in use in the navies of *England*, *France*, and *America*.

1. In 1837, the Lords Commissioners of the Admiralty appointed a committee of scientific and practical men to consider the subject of ships' compasses, and the instrument constructed by them is used as the standard in the navy. It answers the purpose of a steering compass and an azimuth compass.

The *bowl* is of stout copper with a view to calm the vibrations of the needle, and the intersecting point of the axes of its gimbals is made to coincide with the point of suspension of the card, and also with the centre of the azimuth circle. The bowl may be released from the ordinary gimbal suspension and hung in vulcanized india-rubber, when necessitated by great oscillation arising from powerful engines.

The *magnetic needles* employed are compound bars, formed of laminæ of clock-spring steel, which is capable of receiving the greatest magnetic power. Each card is fitted with four needles, fixed perpendicularly to and equi-distant on a light framework of brass screwed to the card; the pair of central needles are each 7·3 inches long and the pair of external ones each 5·3 inches; the extremities of the pairs of needles are respectively

15° and 45° from the extremities of the diameter of the card which is parallel to them. This arrangement renders the action of the card uniform; the needles being so arranged as to give equal moments of inertia for all diameters of the card when vibrated. Balancing slides are attached to adjust for alterations in dip.

The *card* is formed of a mica plate, on which the paper is cemented before the impression of the rhumbs is made; distortions from shrinking being thus prevented and a more perfect centering attained. Two cards, A and J, are supplied with each compass; the former being that in ordinary use, the latter being substituted for it in stormy weather, when the ship is subject to much motion. The whole weight of the lighter card A, with framework and needles, is 1525 grains.

Pivots are furnished adapted for use with the two cards. For card A, two pivot-points are supplied tipped with "native alloy," which is harder than steel, and does not corrode by exposure to the atmosphere, and two spare pivots pointed with hardened steel, electrically gilded. The pivot-caps are of ruby or agate. For card J, two pivot-points are supplied which are ruby tipped; the pivot-cap is coated with speculum metal. There is an apparatus at the side of the bowl for lifting the card off the pivot to preserve it from injury when moving the compass or exercising heavy guns.

The magnetic axis of the needles points to the zero of the card; the various adjustments for centering, and the elimination of errors due to the displacement of sight-vanes and of prism, are all carefully made at the compass observatory at Deptford.

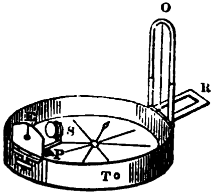
[See "Instructions for the Use of the Admiralty Standard Compass."]

2. The standard compass in the United States Navy is *Ritchie's Liquid Compass.* This consists of a skeleton card mounted on a pivot, and having the bowl filled with a liquid composed of thirty-five parts of alcohol and sixty-five parts of distilled water, the freezing point of the mixture being 10° F. For arctic voyages pure spirit is used. The needles, two in number, consist each of six laminæ of "Stubb's Sheet," a steel of uniform excellence and high magnetic capacity. Each needle is 6½ inches long,

and weighs a little less than two ounces. These needles are enclosed in two tubes placed parallel to the N. and S. line, and connected at their centres by a third tube; this last supports the cap upon which the card is pivoted. These tubes also serve as air-chambers and give great buoyancy to the card. One point of excellence in this compass is the very small amount of friction on the pivot.

3. In the French Navy the regulation compass is *Duchemin's*. The magnet consists of two concentric circular magnetic rings with a diametrical bar connecting the poles. The maxima of the magnetization of the rings is at the N. and S. points, and the power diminishes gradually to zero at the E. and W. points. The card is a star, with eight points carrying a rim with the intermediate graduations. One good feature of this compass is the great fixity of the lines of its poles.

Compass, Azimuth Prismatic.—A compass of very superior construction, specially fitted for taking bearings. On board ship it is mounted on a stand in a commanding position, so that an observer can sweep the horizon; and it is furnished with a pair of sight-vanes for observing objects elevated above the horizon. These vanes are fixed, with hinges diametrically opposite to each other, to a rim concentric with the compass-card, and moving freely upon its centre horizontally. Of this pair the "object-vane" (O) is an oblong frame having a fine thread or wire stretched along its middle, by which the point to be observed is intersected. It is also furnished with a reflector (R), which by a hinge can be directed either below or above the horizontal plane passing through the observer's eye. This enables the observer to take the bearings of objects much below and above his own level. The "eye-vane" (E) consists of a plate having a very narrow slit, which forms the sight through which vision is directed in taking an observa-



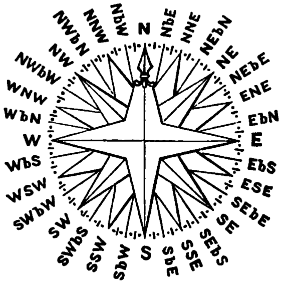
tion, the "line of sight" passing directly over the centre of the compass-card. This slit is enlarged at its lower extremity into a circular hole, through which the graduations of the compass-card are read by reflection in a *prism* (P) attached to the vane. The plate in which this prism is fixed slides in a socket, and thus admits of being raised or lowered as required. Distinct vision of the graduation of the compass-card is thus obtained; and if the slit of the eye-vane be brought immediately over any division, that division, as thus seen by reflection, will appear to coincide with the thread of the object-vane, which is viewed directly. The eye-vane is furnished with a set of dark glasses (S), to be used as shades when the sun is the object observed. The compass-card is very carefully and minutely graduated; besides the points and quarter-points being marked, the circumference over which the prism passes is graduated in degrees, and usually cut to every twenty minutes; and this graduation is arranged so that we may read off the bearing at once, and is reckoned in more ways than one, for facilitating taking bearings from different cardinal points. The card can be brought to a rest by a stop (T) in the case, but this is not generally used in taking bearings at sea. The compass-card often has some motion on board ship, and the card may not be stopped exactly in the middle of its vibration, which is essential to a true result. Instead of using this mechanical contrivance to obtain accuracy in reading off, dependence is rather placed on celerity of observing; the mean of two or more observations taken quickly furnishes the most reliable result. There is also a contrivance for throwing the card off its centre when the instrument is not in use, to prevent the fine pivot being worn, and the sensibility of the instrument being impaired.

Compass, Sir William Thomson's.—This is a marine azimuth and steering compass with adjuncts for the complete application of Airy's principles of correction for iron ships. The great size of the needles in other compasses renders the correction of the quadrantal error for all latitudes, by masses of soft iron placed on the two sides of the binnacle, practically unattainable; and it limits, and sometimes partially vitiates, the other chief part of the correction or that which is performed by means of magnets placed in the neighbourhood of the compass. The special characteristic of Thomson's compass is that the needles are short, and of low magnetic force. To correct the quadrantal error a pair of solid or hollow iron globes, placed on supports, are attached to the binnacle on two sides of the compass; and when once this is accurately done, the correction remains perfect to whatever part of the world the ship may go. Into the binnacle are introduced adjustable sets of magnets for perfectly correcting the error of the compass for every position of the ship's head when she is on even beam, and an adjustable magnet below the compass, perpendicular to the deck, for correcting the heeling error. Steadiness of a compass at sea is proved to depend upon the longness of vibrational period which is secured by giving a large diameter to the compass-card, and by throwing to its outer edge as nearly as possible the whole mass of rigid material which it must have to support it. In place of the old prismatic azimuth arrangement, this compass is furnished with an azimuth mirror founded on the principle of the camera lucida. [For a full description, see "Journal" of the Royal United Service Institution, 1878, Vol. xxii., No. xciv.]

Compass-Card.—It is most important to understand clearly what the compass-card represents. It is balanced so as to be parallel with the *plane of the horizon*, and, by the power of the magnet which is fixed to it, it remains stationary, while the ship, which carries its pivot, revolves below it. It may be regarded then as identical with the horizon of the observer, and its graduated circumference indicates the division of the horizon. Radii of this circle were formerly called *rhumb-lines* (from a Greek word meaning a "whirl"), and they marked out the direction of a ship's course or the bearing of any object.

The circumference of the compass-card is divided according to two systems of notation into points or degrees.

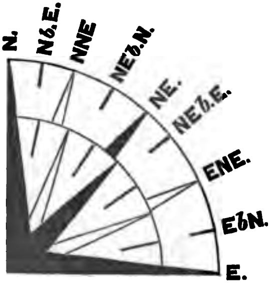
1. *By Points.*—There are 32 points, each of which contains 11° 15'.



The names of the four principal, or, as they are called, the Cardinal Points, are North (written N.), South (S.), East (E.), and West (W.); the east being towards the right when the observer faces the north. The rest of the points are named by a combination of these four words. The four points (which may be called the Secondary Points) mid-way between the several pairs of cardinal points, take their names from the pair between which each lies. They are the North-East (N.E.), North-West (N.W.), South-East (S.E.), and South-West (S.W.). Again, the eight points (which may be called the Tertiary Points) mid-way between each cardinal and adjacent secondary point are named on the same principle, by compounding the names of the points between which each lies. Thus, the point half-way between N. and N.E. is called North-North-East (N.N.E.); and so we have E.N.E., E.S.E., S.S.E., S.S.W., W.S.W., W.N.W., N.N.W. The remaining sixteen points (which may be called the Subordinate Points, or By-points) are reckoned from the cardinal or secondary point to which each is adjacent, the name of which it takes qualified by the name of the succeeding cardinal point towards which it lies. Thus the point next to N. towards E. is called North *by* East (N. *b.* E.), that next to N.E. towards the North is called North-East *by* North (N.E. *b.* N.); and so we have N.E. *b.* E., E. *b.* N., E. *b.* S., S.E. *b.* E., S.E. *b.* S., S. *b.* E., S. *b.* W., S.W. *b.* S., S.W. *b.* W., W. *b.* S., W. *b.* N., N.W. *b.* W., N.W. *b.* N., N. *b.* W. The points of the compass are frequently spoken of with reference to their position to the right or left of the cardinal point towards which the spectator is looking; thus N.N.E. is said to be "two points to the right of North;" W.N.W. "six points to the left of north." Each point is again subdivided into half-points and quarter-points, and these are named upon the same principle as the subordinate points. Thus the division half-way between E.N.E. and E. *b.* N. is called either East-North-East *half* East (E.N.E. ½ E.), or East by North *half* North (E. *b.* N. ½ N.). In choosing the name to use we must be guided by circumstances. In some problems it is convenient always to reckon uniformly from north or south, but generally the simpler name will be the preferable one. And similarly for quarters and three-quarters of a point.

2. *By Degrees.*—The whole circumference is divided into three hundred and sixty degrees (360°), each degree containing sixty minutes (60′), and each minute sixty seconds (60″); the limb being generally cut to twenty minutes. This furnishes a notation for the compass more minute than points, half-points, and quarter-points. We still reckon from the cardinal points; thus, to indicate a division which lies 73° 54′ 30″ to the east of north, we write N. 73° 54′ 30″ E.

Compass-Card, Modified.—A card in which the cardinal points coincide with their proper positions, but the graduations in each quadrant are distorted in such a manner as to correspond with the disturbances of the needle due to quadrantal deviation. Quadrantal deviation, being the result of induced magnetism, is the same in all parts of the earth, for the new or disturbing force is always in the same *ratio* to the primary force which calls it into being. Hence the same modification of the compass-card which correctly alters the apparent card-reading in one part of the earth will correctly alter it in every other part. This correction, then, can conveniently be made



on the card itself, instead of its being embodied in the Table of Deviations or the error compensated by the introduction of horizontal masses of soft iron near the compass. What seems to have prevented this simple and beautiful contrivance of Astronomer Royal Airy being generally adopted is that each iron ship would require a special card; but the adaptation of a skeleton card could not involve more trouble than the arranging of compensating masses of iron near the compass. It may easily be constructed if the coefficient D is known. The annexed figure represents a quadrant of a modified card.

Compass-Card, Dumb.—A card without a needle, which can be substituted for the regular needle-attached card in an azimuth compass, or mounted on a special stand. It forms thus a simple azimuth instrument, independent of the magnet, its purpose being merely to determine the true bearing of the ship's head with reference to another object of which the true or correct magnetic azimuth is known. The practical way of proceeding is as follows:—(1) The true azimuth of a celestial body having been found by calculation, the rim carrying the vanes is screwed to the dumb-card with its index on the graduation giving the true bearing of the heavenly body. This body being then brought on the line of sight at the time for which the calculation was made, the lubber's-point will indicate the reading on the card, giving the true azimuth of the ship's head. (2) Instead of a celestial body, a terrestrial object, whose correct magnetic bearing is known, may be used. When a ship is swung for deviations, the dumb-card is thus very convenient for bringing the ship's head on the correct magnetic bearings which are successively required. This instrument is sometimes called the **Pelorus** with reference to the tradition connected with Cape Pelorus, in Sicily.

Compass—I. **Imperfections**, II. **Adjustments**, III. **Errors**, *of the Instrument.*

I. **Imperfections**, or essential defects, which should lead to the rejection of the instrument.

1. *The pivot must be in the centre of the graduated circumference of the card.*—To examine whether there is an imperfection in this point, observe the difference of bearing between two objects measured on different parts of the circumference. If there be no imperfection, this difference will be the same at whatever part of the arc it is measured.

2. *The eye-vane and the object-vane must each be vertical.*—Examine on shore whether they coincide throughout their length with the direction of the plumb-line.

3, 4.—There are two other imperfections, which, however, do not prevent correct results being obtained, if they are recognized as "errors"—which see.

II. **Adjustment**, where machinery is attached to the instrument, by which it may be put into order.

The needle with card must work on its pivot horizontally.—The "dip" causes the needle to deviate from the horizontal, and as the amount varies in different places, and also goes through cycles of change at the same place, the needle is furnished with sliding weights, by the movement of which it may always be brought to the horizontal. A compass which is not furnished with these appliances may be adjusted by dropping sealing-wax on one end of the needle.

III. **Errors**, acknowledged, and their effects allowed for or eliminated.

1. *The direction of the magnetism of the needle, or the "magnetic axis," must be parallel to the longitudinal line of the needle*, which then points with exactness to the magnetic north and south. To examine whether this is the case, place the needle with its reverse side on the card; the north point of the card, if there is no imperfection, will still point in the same direction as before, as indicated by a mark in the lining of the box. As this error obviously affects all points of the compass alike, it may be included in the total variation of the particular compass as found by observation, and therefore need not be made the subject of separate examination. It is acknowledged and allowed for, like the "index-error" of the sextant.

2. *The line joining the eye-vane and the object-vane, called the "line of sight," must pass directly over the pivot.* To test this, note carefully the bearing of a distant object, and then turn the compass half round, so as to reverse the vane and the slit, repeating the operation with another object eight points from the first. The bearings taken directly should be identical with those taken by reversion. The effects of this error may be eliminated by taking the mean of the direct and reversed bearing every time the instrument is used.

Compass Corrections.—The corrections of the compass are those angles which must be applied to the indications of the instrument to obtain the reading that would be given if the north point of the compass-card corresponded to the north point of the horizon. There are two principal corrections, *variation* and *deviation.* Variation is the disturbance caused by terrestrial magnetism, and varies with geographical position. Deviation is a further disturbance arising from the effect of magnetic influences in the ship itself which carries the compass. There is a third correction sometimes necessitated by disturbances arising from "local attraction" extraneous to the ship, and to which the

Fig. 1.

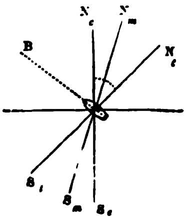
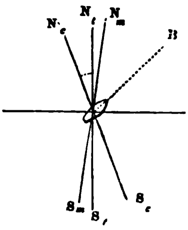


Fig. 2.



unappropriated term "*deflexion*" might be specially applied. Omitting this last, the manner in which these corrections are applied will be best seen by drawing lines to represent the compass north and south line or meridian N_c S_c, the magnetic meridian N_m S_m, and the true meridian N_t S_t. The variation is the angle between N_t S_t and N_m S_m, and the deviation is the angle between N_m S_m and N_c S_c. To deduce the true from the compass course or bearing, N_c S_c (fig. 1) is first drawn; then, according as the deviation is east or west, N_m will be to the west or east of N_c. Again, N_m S_m being now drawn, N_t will be to the west or east of N_m, according as the variation is east or west. N_c N_t is the resulting entire correction to be applied. Thus, if N_c B is a compass course or bearing, by applying N_c N_t the true course or bearing N_t B is found. The entire correction is obtained directly at sea by amplitude and azimuth observations, and might, in its total form, be applied at once to the compass indications if an observation were made for every direction of the ship's head during the day. When it is required to deduce a compass course from a true course, the converse process to the above is pursued. N_t S_t (fig. 2) is first drawn; then, according as the variation is east or west, N_m is to the east or west of N_t; again, N_m S_m being now drawn, N_c is to the east or west of N_m, according as the deviation is east or west.

Compass Compensations.—The mechanical modes of neutralizing or reducing large deviations of the compass by fixed magnets or masses of soft iron.—See **Compass Deviation in Iron-built Ships.**

Compass, Variation of.—The angle which the direction of the magnetic needle makes with the meridian. It is said to be *Easterly* when the north end of the needle is drawn to the eastward, and *Westerly* when it is drawn to the westward of the true north. The variation is different in different places. In any given place it goes through a cycle of change, becoming alternately east and west; it also changes slightly at different times of the day and periods of the year.

Variation is one of the "corrections" in deducing the true course or bearing from the course and bearing observed with the compass. It is given on the charts used in navigation.

To determine the variation.—Compare the bearing of the sun or other celestial body as shown by the compass with the true bearings as found by observation and calculation. The difference of the two bearings will be the total deflection of the magnetic needle due to terrestrial variation and deviation. If the observation is made with a compass on shore uninfluenced by local and ship attraction, the variation is at once obtained; when the observation is made on board ship, in order to obtain the variation as a separate result, the deviation must be known. The true bearing for the above purpose is obtained by computation either of the **Amplitude** or **Azimuth**. The variation may likewise be obtained by comparing the true and compass bearings of some terrestrial object.—See **Bearing.**

Compass, Deviation of.—The angle through which the iron on board ship causes the compass-needle to be deflected from the magnetic meridian. It is said to be *Easterly* when the north end of the needle is drawn to the eastward, and *Westerly* when it is drawn to the westward of the magnetic north.

Deviation is one of the "corrections" in deducing the true course or bearing from the course and bearing observed with the 'compass. It is determined before the ship leaves harbour, and a Table with its amount for every direction of the ship's head inserted in the cover of the log-book. To do this requires the process called "**Swinging the Ship,**" which see.

When the deviation is large, it is compensated or reduced by the application of mechanical contrivances.

Compass Deviation, Constant, Semicircular, Quadrantal.—In all vessels, whether built of wood or iron, the deviation consists of two principal constituent parts, the "*Semicircular*" and the "*Quadrantal,*" with the occasional addition of a small "*Constant*" part. Each of these is in itself subject to regular laws, and any apparent irregularity arises from different combinations and super-position of the parts.

1. *Constant Deviation.*—As far as this is a true deviation, it is small in amount and does not change with a change of latitude. It appears when the soft iron is not symmetrically arranged on each side of the fore-and-aft midship section, or when the compass is not on the midship fore-and-aft line. It arises from terrestrial induction. The coefficient of this part of the deviation is A.

An *apparent* constant deviation is introduced by index or other instrumental errors, or by errors in the assumed direction of the magnetic meridian.

2. *Semicircular Deviation.*—As the ship's head moves round a complete circle in azimuth, this part of the deviation is easterly in one semicircle and westerly in the other: hence its name. The "neutral points," or where the semicircular deviation is zero, are opposite to one another—in wooden ships coinciding nearly with the magnetic meridian, and in iron ships being determined by the position of the ship while building. This deviation, or more exactly the sine of its amount in each semicircle, is approximately proportional to the sine of the azimuth of the ship's head, measured from the neutral points, as shown by the disturbed compass. The semicircular deviation changes with a change in geographical position. This deviation is caused partly by sub-permanent magnetism, and partly by vertical induction in the iron of the ship. The horizontal part of this force is resolved in two directions, one acting in the fore-and-aft line of the ship (+ when drawing the marked end of the needle forward, − when drawing it aft), and the other acting athwartships (+ when drawing the marked end of the needle to starboard, − when drawing it to port). The coefficients of these are severally B and C.

3. *Quadrantal Deviation.*—As the ship's head moves round a complete circle in azimuth, this part of the deviation is alternately easterly and westerly in the four quadrants: hence its name. The "neutral

points," or where the quadrantal deviation is zero, coincide very nearly with the cardinal points. This deviation, or more exactly the sine of its amount, is proportional to the sine of twice the azimuth of the ship's head measured from a line half-way between the direction of the magnetic meridian and that of the disturbed needle. The quadrantal deviation remains unchanged in all magnetic latitudes. This deviation is caused by the transient magnetism of horizontal iron in the ship derived from terrestrial induction. This force is resolved in the same directions as the sub-permanent force. The coefficients are severally D and E.

Compass, Heeling Disturbance of Deviation.—The compass on board ship is adjusted when she is on an even beam, the necessary compensations being made, and the Table of Deviations drawn up under that condition. In iron-built ships, and also in those constructed of wood with iron beams, the deviation is greatly affected by the heeling of the ship, and the values before established and recorded are thus disturbed. An additional mechanical compensation may be introduced, or the requisite modification applied as a correction.

The causes of this disturbance will be understood by bearing distinctly in mind that it arises partly from the change in the action of the sub-permanent magnetism of the ship, and partly from a changed development of induced magnetism. (1) It is the horizontal components of the ship's magnetism that affects the direction of the needle; and when a ship heels, forces which before acted vertically, and therefore did not disturb the horizontal needle, now act on one side, and produce deviation. (2) New forces develop in iron (such as iron decks), which, previously horizontal, becoming inclined, receive magnetism by induction from the earth's vertical magnetism.

The general law of the effect of heeling is thus given in Airy's Syllabus. When a ship's head is east or west, no sensible effect is produced by heeling. When the ship's head is north or south, heeling produces the greatest effect. Usually, but not in all cases, the marked, or north, end of the needle is attracted to the windward or raised side of the ship in north latitudes, and the unmarked, or south, end in south latitudes. Often in iron ships, with ship's head north or south, one degree of heel produces one degree of disturbance of the compass, but in some instances one degree of heel produces two degrees of disturbance of the compass; in many of our men-of war it does not exceed half a degree.

Compass Deviation Formulæ.—The deviation may be expressed in algebraical formulæ, the several terms of which represent the constituent parts arising from the different forces acting upon the compass, resolved in definite directions. Some of these formulæ are approximate, others exact. For each ship the coefficients are determined by experiment, and then the formula gives the deviation for any direction of the ship's head. The following summary is abstracted from the "Admiralty Manual," which gives Poisson's general theory, and A. Smith's investigations.

1. If the deviation is of moderate amount, not exceeding 20° on any point, it is expressed with sufficient exactness, for practical purposes, by the *approximate formula.*

$$\delta = A + B \sin \zeta' + C \cos \zeta' + D \sin 2\zeta' + E \cos 2\zeta'.$$

In this expression δ is the deviation, reckoned + when the north end of the needle is drawn to the east, − when drawn to the west. ζ' is the compass course or the azimuth of the ship's head from the direction of the disturbed needle, reckoned + to the eastward, − to the westward. $\zeta' + \delta$ is therefore the magnetic course, or the azimuth of the ship's head from the direction of the magnetic north, or of the undisturbed needle, reckoned + to the eastward, − to the westward.

In this expression—

A is the *constant* deviation,

$B \sin \zeta' + C \cos \zeta'$ is the *semicircular* deviation;

$D \sin 2\zeta' + E \cos 2\zeta'$ is the *quadrantal* deviation.

When the compass is on the middle fore-and-aft line of the ship, the coefficients A and E are generally so small that they may be neglected. The expression for the deviation then becomes—

$$\delta = \text{B} \sin \zeta' + \text{C} \cos \zeta' + \text{D} \sin 2\,\zeta'.$$

In this case, therefore, there is no constant deviation; the semicircular deviation is B sin ζ' + C cos ζ'; the quadrantal deviation is D sin 2 ζ'.

Again: B is approximately the deviation at east; and, with changed sign, at west. C is approximately the deviation at north; and, with changed sign, at south. D is the mean of the deviations at N.E. and S.W.; and, with changed sign, at S.E. and N.W.

The coefficients A, B, C, D, E, are best determined from observations of deviation made with the ship's head on a certain number of equi-distant points. When we can observe only on a small number of points equally distributed round the horizon it is necessary to use in every case the following exact expression for the deviation:—

2. *Exact formula*, to be used when the deviation, on any course, exceeds 20°.

$\text{Sin}\,\delta = \mathfrak{A} \cos \delta + \mathfrak{B} \sin \zeta' + \mathfrak{C} \cos \zeta' + \mathfrak{D} \sin (2\,\zeta' + \delta) + \mathfrak{E} \cos (2\,\zeta' + \delta)$ where the coefficients, $\mathfrak{A}$, $\mathfrak{B}$, $\mathfrak{C}$, $\mathfrak{D}$, $\mathfrak{E}$ are nearly, but not exactly, the natural sines of the coefficients A, B, C, D, E.

3. *Ship not on an even beam.* When the ship heels over i° ($+\,i^\circ$ representing a heel to starboard, $-\,i^\circ$ a heel to port) the approximate expression—

$$\delta = \text{B} \sin \zeta' + \text{C} \cos \zeta' + \text{D} \sin 2$$

becomes, very nearly,

$$\delta_i = \text{B} \sin \zeta' + \left\{ \text{C} - \left(\mathfrak{D} + \frac{\mu}{\lambda} - 1\right) \tan \theta\, i^\circ \right\} \cos \zeta' + \text{D} \sin 2\,\zeta'.$$

In this expression: θ is the dip;

$$\lambda = \frac{\text{Mean directive force of needle on board}}{\text{Directive force on shore.}};$$

$$\mu = \frac{\text{Mean value of vertical force on board}}{\text{Vertical force on shore.}}.$$

The effect of the heeling is therefore to add to the deviation the term $-(\mathfrak{E} + \frac{\mu}{\lambda} - 1) \tan \theta\, i^{\circ} \cos \zeta' = \mathrm{J}\, i^{\circ} \cos \zeta'$, which is the *heeling error*; and J is called the *heeling co-efficient.*

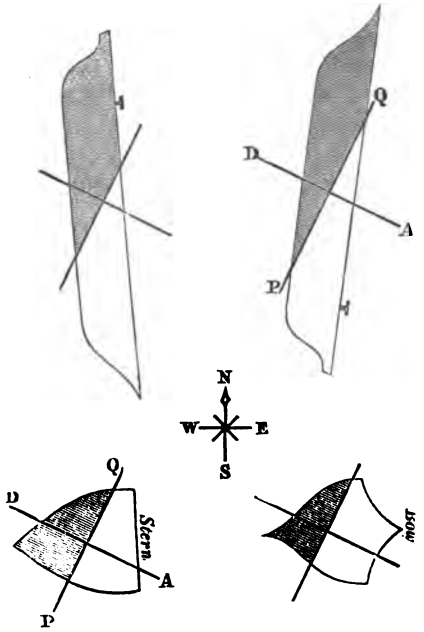
When $\zeta' = 90^{\circ}$ or 270°, that is, when the ship's head is E. or W. by compass, the heeling error $= 0$; when $\zeta' = 0^{\circ}$ or 180°, that is, when the ship's head is N. or S. by compass, the heeling error = maximum. In the northern hemisphere, $\tan \theta$ being $+$, and $(\mathfrak{E} + \frac{\mu}{\lambda} - 1)$ being generally $+$, the heeling error will generally have the opposite sign to i°, that is, will cause a deviation of the north point of the needle to windward.

Compass Deviation in Wood-built Ships.—The quantity of iron in these ships is comparatively small, it is in most cases equally distributed in both sides of the ship, and it is not exposed to mechanical violence after being fixed in its position on board. Hence, the disturbance it produces is small, the magnetism of one mass of iron counteracting, in a great measure, that of another, and the slight permanent magnetism of the ship has no general character. As a general rule, the deviation is at its maximum when the ship's head is near east and west by compass. The machinery of a steamer and the armament of a ship-of-war introduce some modifications. The chief disturbing action of the iron in a wood-built ship arises from the magnetism which is transiently induced by the earth's magnetism giving rise to a semicircular deviation. Captain Flinders, at the commencement of this century, detected this; and, referring the changes in the errors of his compass on different sides of the magnetic equator to the induced magnetism in the vertical iron stanchions ahead of the compass, suggested that this might be counteracted by a vertical iron bar introduced astern of the compass. This is the earliest recognition of the modern principle of compass compensation.

Compass Deviation in Iron-built Ships.

(I.) *Disturbing Forces acting upon the Compass.*

The influences causing deviations in the compass of an iron-built ship are of two distinct characters. (1.) The ship itself is a true magnet, possessing sub-permanent magnetism, the position of its poles depending upon the direction of the ship while building. The annexed figures exhibit the magnetic condition of ships built in the extreme positions, head north, south, east and west. Red magnetism is shaded here with transverse lines. QP is the equatorial plane, and AD the axis of terrestrial force or direction of dip. There are therefore three true magnets to be considered; (*a*) The earth, the magnetism of which varies in force and direction in different parts of its surface; (*b*) the ship, which is a constant magnet passing over this surface, quite independent of it, and turning its poles in all directions; and (*c*) the small compass needle suspended on board the ship, which thus interferes with its obedience to the terrestrial influence.

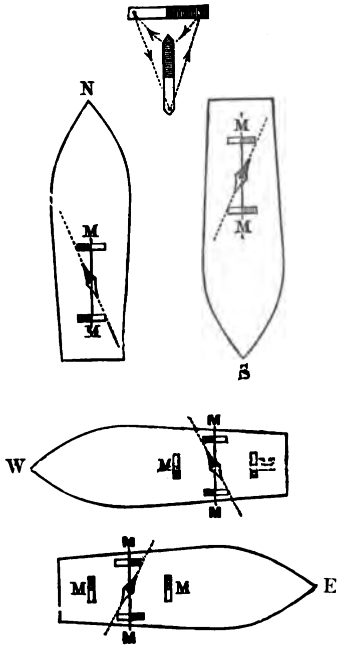


(2.) Portions of the ship, such as vertical iron rods, which are often nearly in the direction of the earth's total force become transient induced magnets. Unlike the sub-permanent magnetism of the ship, this is dependent for the time being upon the terrestrial magnetism, and will vary with it in different parts of the world. In addition, then, to the three magnets, referred to above, we have (b') Portions of the ship which become transient magnets by induction of the earth. In the accompanying figures (p. 103) this induced magnetism is represented by the marked end being shaded longitudinally. N. and S. mean magnetic north and south.

(II.) *Resolution of Total Disturbing Forces into Horizontal and Vertical.*—Just as the terrestrial magnetic force is resolved horizontally and vertically, the disturbing forces are resolved into corresponding components. These disturbing forces may be considered as equivalent to a permanent and induced magnet, and each is separately resolved into a horizontal and vertical component, the former being again resolved into two sub-components. The horizontal forces affect the direction of the compass needle directly, the vertical forces affect it indirectly, and the former are considered first. We have, therefore, the four component forces in order:—

i. 1. Horizontal Sub-permanent.
ii. 1. Horizontal Induced.
i. 2. Vertical Sub-permanent.
ii. 2. Vertical Induced.

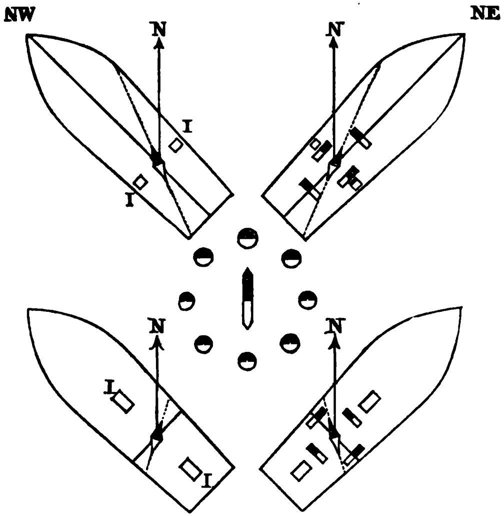
(III.) *Principle of Compensating the Disturbing Forces.*—Astronomer Royal Airy gives this in a few words:—"The only way of destroying the effect of one magnetic disturbing force is to introduce another disturbing agent, whose force follows the same laws and has the same magnitude, but always acts in the opposite direction." Sub-permanent magnetism is corrected by the agency of a counteracting permanent magnet; and transient magnetism by counteracting masses of soft iron, which become similarly affected by induction, being converted into transient magnets. The horizontal components are corrected by magnets or masses of iron placed in horizontal positions; the vertical by magnets or masses of iron placed in vertical positions. These magnets and masses of iron are so introduced that their influence may neutralize the disturbing forces. This is the general principle; the following are the different steps of the process.



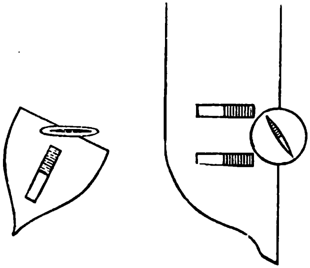
(IV.) *Method of Compensating the Component Disturbing Forces.*—(i. 1.) *Horizontal Sub-permanent Magnetism.*—This disturbance appears as a semicircular deviation, and the correction is made for direction of ship's head N. (which corrects it for S. also), and for direction of ship's head E. (which corrects it for W. also). For each of these two directions the compensation is effected by a magnet, or pair of magnets, which are always, when placed, transverse to the magnetic meridian. The process is represented in the annexed figures, where the dotted lines indicate the direction of the needle as affected by the semicircular deviation; the continuous lines the direction after the correcting magnets have been introduced. First placing the ship N. and S., we introduce the magnets MM, approaching them gradually till the dotted line is made to coincide with the continuous one, or till the oscillations of the needle are equal on each side of it. Next the ship is turned E. and W., and the deviation which then appears is corrected by a second magnet, or pair of magnets

(MM), placed as before, athwart the meridian. The first pair of magnets (MM) have no effect in this position, the action of the two sets being independent. The figure at the top of the diagram depicts the action of a compensating magnet upon the needle.

(ii. 1.) *Horizontal Induced Magnetism.*—This is the next component that should be corrected. It appears as a quadrantal deviation. When the ship is N. and S. the induced magnetism of the iron on board produces no disturbance, and similarly when the ship is E. and W. The greatest effect is produced when the ship lies N.E. and S.W. or N.W.

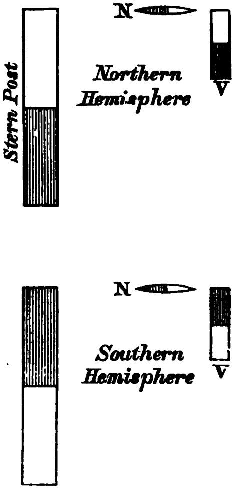


and S.E., and therefore we must apply the compensation for these positions. If the correction be rightly done on one quadrantal point it should be right for all. The effect of the horizontal component of the induced magnetism is, in the majority of cases, to draw the needle in the direction of the ship's length, but sometimes the needle is deflected towards a line drawn in the direction of the beam of the ship. In the figures we have shown both cases. The compensation is effected by the application of a mass or pair of masses of soft iron placed transversely to the direction of the line towards which the needle is deflected, whether this be fore-and-aft or athwart-ship. The figure in the centre of the diagram depicts the action of a mass of iron under horizontal induction in different positions round the needle.



(i. 2.) *Vertical Sub-permanent Magnetism.*—This has no disturbing influence on the horizontal deflection of the compass needle so long as the ship is on an even beam; but, when she heels, a deviation results from it of sometimes 1° for every 1° of heel. The reason of this is evident, for what was entirely a vertical force is now an oblique one, a portion of which is resolved in the horizontal plane, and this secondary horizontal component of what was originally the vertical component has an effect on the direction of the compass needle. A portion of the original horizontal force becomes at the same time vertical; so that it is strictly the difference that has to be corrected. This correction is effected by fixing a magnet or pair of magnets vertically below the needle, when the ship is on an even beam. Which end should be up may be understood by considering the extreme case when the ship is on her beam ends, and when therefore the correcting magnet will be in the same horizontal plane with the compass needle; it can only be practically ascertained by the aid of a special instrument. The case shown in the figure requires the red end to be up.

(ii. 2.) *Vertical Induced Magnetism.*—This is counteracted by introducing soft vertical rods which are affected by the same induction, but placed in positions where the influence on the compass acts in the opposite direction. The stern-post is one of the most powerful disturbing induced magnets on board a ship, its red end being downwards in northern magnetic latitude and upwards in southern magnetic latitude. The correction for this is made by placing a vertical rod of soft iron, V, ahead of the needle.



(V.) *Alternatives in Place of Compensating.*—In the case of sub-permanent magnetism (i. 1. and i. 2.), the amount of the deviation depends upon the ratio of the disturbing force to the terrestrial magnetism; and this ratio varies not only with the direction of the ship's head, but with her geographical position. The necessary corrections may be recorded in *Tables*, and applied to the indications of the compass; these tables being revised in different parts of the world.

In the case of induced magnetism (ii. 1.), the ratio which the disturbing force bears to the terrestrial magnetism (which induces it) is always the same, and therefore the amount of the deviation is the same (for the same direction of the ship's head) in whatever part of the world the ship may be. The use of a *Modified Compass Card* obviates the necessity of either compensation or a table of corrections, for this part of the deviation. A practical objection to compensation by masses of soft iron, in some cases, arises from the large amount that would be required.

and the close proximity of its position to the compass. The fact of the coefficient D being found in all ordinary cases to be positive, led Staff-Captain F. J. Evans to propose the use of two Admiralty compasses of precisely equal strength, placed in starboard and port binnacles, regulated at a proper distance. The needles of these compasses will produce on each other a negative quadrantal deviation which will correct the positive quadrantal deviation arising from the ship. This mutual action of two proximate compasses was investigated in 1820, by Peter Lecount, Mid., R.N.

(VI.) *Practice in the Royal Navy.*—A place for the standard compass, where it is least affected by the disturbing forces, is carefully selected on board. A magnet is generally introduced for the purpose of equalizing the directive force on different azimuths, and at the same time diminishing the semicircular deviation. The quadrantal deviation is generally left for tabular correction. The heeling deviation is always ascertained, and is sometimes corrected mechanically.

Compass Deviations; Graphic Methods of Treating.—See **Napier's Diagrams and Curve**; **Dygogram.**

Compass Bearing.—The bearing of an object as taken by the compass. It is distinguished from the *true bearing*, which may be deduced from it by applying the corrections for *variation* and *deviation.*—See **Bearing.**

Compass Course.—The angle which the ship's track makes with the direction of the magnetic needle of the compass. It is distinguished from the *true course*, which may be deduced from it by applying the corrections for *variation* and *deviation*. The correction for *leeway* is also necessary to deduce the course made good from the course steered.—See **Course.**

Complement (L. *complēre*, to "complete," "fill up.")—The complement of a quantity is what must be added to it to make up a sum equal to some fixed quantity. The following are the special uses of the term:—

1. In *Arithmetic.*—The number 10, with its powers, is regarded as a standard of completeness, and the "arithmetical complement" of a number is the number which must be added to it to make it up to that power of 10 next higher; *e.g.* the ar. co. of 756 is 1000 − 756 = 244. This is used chiefly in problems worked by logarithms, the arithmetical complement of a logarithm being the difference between the logarithm and 10; *e.g.* the ar. co. of 3·460898 is 6·539102, the ar. co. of $\bar{2}$·636488 is 11·363512.

2. In *Trigonometry.*—A quadrant, right angle, or 90°, is regarded as the standard of completeness; the complement of an arc or angle being what must be added to it to make up the quadrant; *e.g.* the complement of 35° is 55°. Thus, the polar distance is the complement of the declination, or, as it is written, the *co*-declination; the zenith distance is the complement of the altitude, or the *co*-altitude; and we also have the *co*-latitude. Again, the *co*-sine is the sine of the complement, the *co*-tangent the tangent of the complement, the *co*-secant the secant of the complement.

3. In *Geometry.*—The complements of the parallelograms about the diagonal of a given parallelogram are those spaces which together, with those parallelograms, "complete" the containing parallelogram.

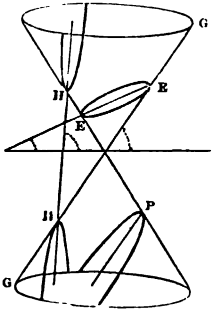
Composite Sailing.— The combination of *great-circle* and *parallel sailing.* A navigator, wishing to take the shortest route between two places, finds that, in the particular case, before him, the great-circle track reaches too high a latitude, where the ice renders it dangerous or impossible for the ship to penetrate. He therefore fixes upon some one parallel of latitude as the maximum; and the shortest route, under these conditions, will consist of a portion of that parallel, and of the portions of two great circles which are tangents to it, and which pass one through the ship, the other through the destination. On the central or gnomonic chart, the track will be the two straight lines drawn from the two places so as to touch the circle of highest latitude, and the part of this circle between the points of contact.

Con-, Co-, Com-, Col- (L. *con-*, a prefix signifying "with." In the use of this prefix before a vowel or *h* the *n* is dropped; and before *l* and *m* it is changed into these letters respectively).—An adjective with this prefix indicates that the things qualified possess the feature named in common: thus, *concentric*, having a common centre; *co-axial*, having a common axis; and similarly in *co-extensive*, *co-incident*, *co-terminal* and *commensurate*. There are also certain substantives in general use with the same prefix: thus, *co-ordinates* are a set of lines or planes disposed in a predetermined order, which taken *together* define the position of a point; a line of *collimation* in a telescope is the line of sight which brings *together in one* the centre of the object-glass and the mid-point of the cross-wires placed in the focus. **Co** is also used as a prefix before certain trigonometrical ratios, and arcs of circles. It is here the abbreviation of *complement of*, *e.g.* cotangent, co-latitude.

Conic Sections.—The curves formed by the intersection of a cone by a plane. They are of three kinds—the *Parabola* (Gk. *παραβάλλειν*, "to place side by side"), the *Ellipse* (Gk. *ἐλλείπειν*, "to fall short of"), and the *Hyperbola* (Gk. *ὑπερβάλλειν*, "to exceed"); in the first (P) the cutting plane is "parallel" to the generating line of the cone (GG), in the second (E) its inclination to the base is "less" than in the parabola, and in the third (H) it is in excess,—hence the names. To persons acquainted with analytical geometry, the distinctive properties of the three are exhibited by their respective equations—

$$y^2 = px, \quad y^2 = px - \frac{b^2}{a^2}x^2, \quad y^2 = px + \frac{b^2}{a^2}x^2.$$

The ellipse is the most important to the nautical student.



Conjunction (L. *conjunctio*, from *con*, "together;" *jungĕre*, "to join.")—Heavenly bodies are said to be in conjunction when they have the same longitude, and are therefore seen in the same part of the heavens. In contradistinction to this, when they have a difference of longitude of 180°, and are therefore seen in diametrically opposite parts of the heavens, they are said to be in *opposition*. For example: The moon is in conjunction with the sun at new moon, in opposition at full moon. The inferior planets (Mercury and Venus), instead of having with the sun points of conjunction and opposition, have their *inferior* and *superior conjunctions*—the former when the planet passes between the sun and the earth, the latter when behind the sun. Symbols: Conjunction, ☌; opposition, ☍.

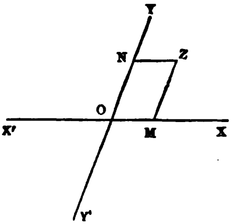
"Connaissance des Temps."—The French work corresponding to our "Nautical Almanac."

Constellation (L. *con*, "together;" *stellatio*, "a grouping of stars," from *stella*, "a star").—A group of fixed stars to which a definite name has been given. These names have mostly their origin in the mythology of the Greeks, derived and modified from the Egyptians and the East; and the stars forming each configuration are ranged and named in order of brilliancy by letters of the Greek alphabet being attached to them—*e.g.* we have *α Ursæ Majoris*, *β Orionis*, etc. The districts of the heavens thus mapped out and thus designated are entirely arbitrary, and in general correspond to no natural subdivision or grouping of the stars; and, as Sir John F. W. Herschel remarks, "the constellations seem to have been almost purposely named and delineated to cause as much confusion and inconvenience as possible. Innumerable snakes twine through long and contorted areas of the heavens where no memory can follow them; bears, lions, and fishes, large and small, northern and southern, confuse all nomenclature." This ancient system has, however, obtained a currency from which it would be difficult to dislodge it; and it serves the purpose of briefly naming remarkable stars—an important point for a navigator.

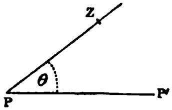
These constellations are most conveniently studied under the three following groups:—(1) North Circumpolar Constellations taking in 45° from the pole; (2) South Circumpolar Constellations, taking in 45° from the pole; (3) Equatorial Constellations, embracing a zone 45° north and 45° south of the equator. One most conspicuous constellation above the horizon in each of these will be sufficient to identify all the rest. In (1) we recommend *Ursa Major;* in (2) *Crux;* and in (3) *Orion* and *Lyra*, these being in opposite parts of the heavens, and one of them, therefore, always above the horizon. These four constellations, taken as starting-points, will enable a seaman easily to learn the position of any other group wanted.

Contraction of Moon's Semi-diameter.—See under **Moon.**

Co-ordinates.—A set of lines, angles, or planes, or combination of these, which, taken together, define the position of the several points of a given surface, or points in space. The method was invented by Descartes, the French geometer, who first expressed algebraically theorems involving the *position* of lines. To represent the position of a curve on a plane, he chose a certain right line, to the different points of which he referred all the points of the given curve; then he chose a certain point in this line from which to commence the reckoning ("ad *ordiendum* ab eo calculum"). Hence the series of lines by which the curve was referred to the chosen line were called *ordinates* (derived from a word of the same root, *ordinare*, "to range in order"), and the portions of the line "cut off" by this series from the chosen point were named *abscissæ* (L. *abscindĕre*, "to cut off"). If, however, *two* lines are taken intersecting each other at a given angle in a fixed point, the several points of the curve in question may be referred to each of them in turn, and thus *two sets of ordinates* be contemplated, which, *taken together*, define every point of the curve; hence the term co-ordinates. 1. To explain briefly this *system of rectilinear co-ordinates for a plane*, XX′ YY′ are two fixed right lines given in position, intersecting each other in the point O. Let Z be any point in the plane. Through Z draw ZM and ZN parallel to YY′ and XX′, then, if we know the position of the point Z, we shall have the lengths of ZM (y) and ZN (x); and, *vice versâ*, if we know the lengths of ZM and ZN we shall know the position of the point Z. In order to define in which of the four compartments about O the point Z is situated, those distances which are measured from O to the *right hand*, and *upwards*, are regarded positive, and those of the *left hand*, and *downwards*, negative. The parallels ZM and ZN are the *co-ordinates* of the point Z; the fixed lines XX′ YY′ are termed the *axes of co-ordinates;* and the point O the *origin*. A plane chart furnishes a good exemplification of the above. XX′ and YY′ intersecting at right angles will represent respectively the equator and first meridian, and the co-ordinates of any place on the chart will be its longitude and latitude.



2. *Polar system of co-ordinates.*—P is a given fixed point called the *pole*, and PP′ a fixed line through it. Then we shall know the position of any point Z if we know the length of PZ, and also the angle P′PZ. This line PZ is called the *radius vector* (ρ), and the angle P′PZ the *polar angle* (θ). The angle is reckoned positive when the radius vector revolves in the direction opposite to that in which the hands of a watch move, negative when it revolves the contrary way.



Co-ordinates for the Surface of a Sphere.—The great circle is to the surface of a sphere what the straight line is to the plane. Hence, by substituting "sphere" for "plane," and "great circle" for "right line," in the last article, we shall have no difficulty in understanding how the position of a point is defined by co-ordinates on this surface. 1. To follow Descartes' original words when describing *rectilinear co-ordinates.* Let a certain great circle ROR'O' be chosen, to the different points of which any point of the sphere may be referred (by arcs of great circles perpendicular to it); then let a certain point (O) be chosen in this great circle from which to commence the reckoning. Thus, the position of the point Z is defined by the arcs of great circles OM and MZ. Here we have the conception (explained in the last article, fig. 1) of *ordinate* and *abscissa*, and hence the usual method of naming the great circles used to refer points to the fixed great circle. They are named after the *ordinate* which is measured on them. 2. But, as it is useful to regard the sphere as a surface generated by the revolution of a circle about one of its diameters, the conception of *polar co-ordinates* is especially applicable and convenient. The angle through which the generating circle revolves is the *polar angle*, and an arc of this circle the *radius vector.* Thus—Let PP' be the diameter of the generating circle, one of the extremities of which (P) may be regarded as analogous to the fixed point P in the polar co-ordinates for a plane (fig. 2 of last article), the fixed great circle POP' analogous to the fixed right line PP', and the great circle arc PZ analogous to the radius vector PZ. Thus the point Z is defined by the angle OPZ and the arc PZ. In this view, the circle passing through Z, being the *generating circle* in a particular

Fig. 1.

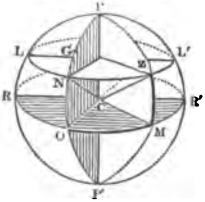
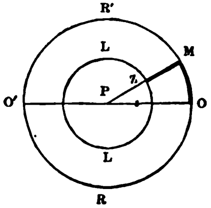


Fig. 2.



position, would be naturally named after the angle swept out from its initial position.

The two conceptions may be advantageously combined. The *ordinate circle* of the first system is the same as the *generating circle* of the second system; the *ordinate* and *radius vector* coincide in direction and are complementary to each other, and are thus convertible, and the *abscissa* and *polar angle* measure each the other, and can hence be interchanged. The surface of a sphere is a limited one, analogous not to an indefinite plane, but to a circular disc. And just as in such a circular disc we may reckon a distance on the radius vector, either from the centre (the pole) or by its complement in the opposite direction from the circumference, so on the surface of a sphere we may reckon the distance of a point on the generating circle either from the pole or from the pole's great circle. If we adopt the latter plan, we find we have substituted *ordinate* for *polar distance*. Again, on the surface of a sphere, the angle at any point and the corresponding arc of the great circle of which this point is a pole may be used indiscriminately for each other; *i.e.* the *polar angle* and the arc of the fixed great circle intercepted from the origin (the *abscissa*) are virtually the same thing. The use of co-ordinates for the surface of a sphere may hence be comprehensively described as follows: A fixed great circle ROR′O′ is chosen as the *primitive*, and another fixed great circle POP′O′ at right angles to this represents the initial position of the *secondary*. These two circles intersect in two fixed points O and O′, which are called the *points of origin*. The secondary circle, or rather one-half of it, POP′, is now conceived to revolve upon the axis PP′ from its initial position. In any given position PMP′, it will mark out all points of a sphere which have the same *polar angle* OPM, or the same *abscissa* OM. Again, in thus revolving, any point in its arc will describe a small circle parallel to the primitive, which parallel will mark out all points of the sphere that have the same *radius vector or polar distance* PZ, or the same *ordinate* MZ. The intersection of the two, the *secondary* and the *parallel*, gives the point Z. It being known, therefore, whether only one (O) or both (O and O′) of the points of origin are to be reckoned from, and in which direction the secondary is to revolve, and again, on which side of the primitive the parallel lies, the position of any point Z is completely defined by its co-ordinates, the polar angle OPM, or the abscissa, the arc OM (= angle at centre OCM), and the radius vector PZ, or the ordinate MZ (= angle at centre MCZ).

The two spherical surfaces with which the navigator is concerned are the terrestrial sphere and the celestial concave.

Co-ordinates for the Terrestrial Sphere.—Co-ordinates, *Longitude* and *Latitude*. The primitive (ROR'O') is that great circle perpendicular to the axis of the earth's rotation—the *Equator;* the secondary semicircle (POP'), in its different positions, generates the *Meridians* or *Circles of Longitude*, each of which (as PMP') marks all the places that have the same *Longitude* (as OM); the initial position of the secondary (called the *First Meridian*) is variously determined upon by different nations from the station of their principal observatory (G); and the secondary is commonly conceived to revolve westward and eastward through 180°; the parallels, called *Parallels of Latitude* (as LNL'), mark all the places that have the same *Latitude* north or south (as ON). Any place (as Z) is defined by the intersection of its circle of longitude (PMP') and its parallel of latitude (LNL'), and its position described by its two co-ordinates, longitude (east, OM) and latitude (north, MZ). When the spheroidal figure of the earth is taken into account, a new definition of latitude is necessary [**Latitude of an Observer**].

Note.—Longitude is usually, as above noticed, reckoned west and east. High authorities, however, recommend that this mode of expression should be abandoned, and longitudes reckoned invariably westward from their origin round the whole circle from 0 to 360°. This would add greatly to systematic regularity, and tend much to obviate confusion and ambiguity in computation. When the secondary is regarded as an *ordinate* rather than a *polar* circle, the meridians will be called *Circles of Latitude*.

Co-ordinates for the Celestial Sphere.—In what follows, the system takes its title from the primitive, and the secondary is viewed as a generating circle:—

1. *Ecliptic System.*—Co-ordinates to describe the points of the celestial concave relatively to each other, and with primary reference to the proper motions of the heavenly bodies—*Longitude* and *Latitude.* The primitive circle (ROR′O′) is the apparent path of the sun in the heavens,—the *Ecliptic;* the secondary semicircle (POP′) in its different positions generates the *Circles of Longitude,* each of which (as PMP′) marks all the points that have the same *Longitude* (as OM); the initial position of the secondary is defined by the *Vernal Equinoctial Point;* and it revolves eastward through 360°; the parallels, called *Parallels of Latitude* (as LNL′), mark all the points that have the same *Latitude* north or south (as ON). Any point (as Z) is defined by the intersection of its circle of longitude and its parallel of latitude, and its position is given by its two co-ordinates,—longitude (OM) and latitude (north, MZ).

2. *Equinoctial Systems.*—(*a*) Great-circle co-ordinates to describe the points of the celestial concave relatively to each other, and with primary reference to the apparent diurnal motion of the heavenly bodies,—*Right Ascension* and *Declination.* The primitive circle (ROR′O′) is that great circle perpendicular to the rotation axis of the heavens,—the *Equinoctial;* the secondary semicircle (POP′) in its different positions generates *Circles of Right Ascension,* each of which (as PMP′) marks all the points that have the same *Right Ascension* (as OM); the initial position of the secondary (called the *Equinoctial Colure*) is defined by the *Vernal Equinoctial Point,* and it revolves eastward through 24^h or 360°; the parallels, called *Parallels of Declination* (as LNL′), mark all the points that have the same *Declination* north or south (as ON). Any point (as Z) is defined by the intersection of its circle of right ascension (PMP′) and its parallel of declination (LNL′), and its position is given by its two co-ordinates,—right ascension (OM) and declination (north, MZ).

(*b*) Polar co-ordinates to describe the points of the celestial concave with reference to the diurnal motion of the heavenly bodies and in connection with the position of an observer on the earth's surface,—*Time* or *Hour Angle* and *Polar Distance.* The initial line is the *Noon Circle*, or, as it is commonly called, the *Celestial Meridian;* the radius vector is the *Time Circle*, or, as it is commonly called, the *Hour Circle*, and the polar angle is the *Time Angle*, or, as it is commonly called, the *Hour Angle.* The noon circle or celestial meridian is defined by the meridian of the place or the zenith of the observer; the time circle revolves from the initial position westward through 24^h; on the time circle is measured the *Polar Distance* from the elevated pole through 180°. The polar distance is thus the complement of a body's distance (+ or −) from that great circle which is, daily throughout the year, 12^h above and 12^h below every observer's horizon—the equinoctial.

3. *Horizon System.*—Co-ordinates to describe the points of the celestial concave with reference to the position of an observer on the earth's surface,—*Azimuth* and *Altitude.* The primitive circle (ROR′O′) is that great circle in which a horizontal plane through the observer's eye meets the celestial concave, and which derives its name from its being the "boundary" of the visible and invisible hemispheres,—the *Horizon;* the secondary semicircle (POP′), in its different positions, generates the *Circles of Azimuth*, each of which (as PMP′) marks all the points which have the same *Azimuth* (as OM); the initial positions of the secondary are defined by the *North* or *South Point* (that one which is most remote from the elevated pole); and it revolves eastward and westward from 0 to 180°; the parallels, called *Parallels of Altitude* (as LNL′), mark all points that have the same *Altitude*, positive or negative (as ON). Any point (as Z) is defined by the intersection of its circle of azimuth and its parallel of altitude, and its position is described by its two co-ordinates,—azimuth (OM) and altitude (+ MZ).

When a body is *in* the horizon, its position is described by its distance north or south of the east or west point, which is called its *Amplitude.*

Note.—If, in the above, the secondary in its different positions were viewed as a series of *ordinate circles* (after the analogy of rectilinear co-ordinates), then these circles would be named after the ordinate which is measured on them. We should thus have "circles of declination", "circles of latitude", "circles of altitude". But we have regarded the secondary as a *generating circle*, and named it after the angle it sweeps out from its initial position, as in polar co-ordinates. The advantage of this method is, that each of these circles thus marks out all points which have the same right ascension, the same longitude, the same azimuth, as the case may be, just as in the series of small circles parallel to the primitive, each parallel marks out all points that have the same declination, the same latitude, the same altitude, as the case may be. Thus also is insured the mention of *both*, instead of one only of the co-ordinates. For example: A point is defined by the intersection of its circle of right ascension and its parallel of declination, which is a more complete form of expression than to say it is defined by the intersection of its circle of declination and its parallel of declination.

Cor Caroli (L. "Charles's Heart").—The name given by Halley to the star 12 *Canum Venaticorum.*—See **Canes Venatici.**

Corona Borealis (L. "The Northern Crown").—A constellation lying between *α Lyræ* and Arcturus. It consists of six or seven stars, forming a small semicircle. *α Coronæ Borealis* (called also *Gemma*), mag. 2; 1882, R.A. $15^h\ 30^m$, Dec. + 27° 7′.

Corrected Establishment of the Port.—The interval between the time of the moon's transit and the time of the high water at the port *corresponding to* the day of syzygy. It is distinguished from the *Vulgar Establishment of the Port*, which is the interval between the time of the moon's transit and the time of high water *on* the day of syzygy.—See under **Tide.**

Corrections.—Corrections are quantities which have to be applied to observed elements before these can be made the subject of computation in the various problems of navigation. Thus in geo-navigation, in a day's work, we want to find the total true course made good; for this computation we should have all the several true courses made good during the day; but what we have noted were the compass courses steered. These compass courses steered must therefore be reduced to the corresponding true courses made good, and this is done by applying the "corrections" for variation, deviation, and leeway. So in the problems of celo-navigation, such elements as the altitudes and distances of heavenly bodies are used. But these are observed with an instrument which may have an index error; the observer is generally elevated above the earth's surface; and often one of the limbs, instead of the centre of the body, is observed. Such an observed element therefore requires the "corrections" for index error, for dip, for semidiameter. But, further, the atmosphere variously affects such observed elements; and the different positions of observers on the earth's surface must be taken into account. For the sake of comparison and computation, all observations must be transformed into what they would have been had the bodies been viewed through a uniform medium, and from one common centre—the centre of the earth; hence the additional corrections for refraction and parallax. It is, however, only a few elements that are the subject of direct observation on board ship; others, as the declination and right ascension, are found by consulting the Nautical Almanac. They are there tabulated for certain Greenwich dates. Before, therefore, we can use them in our calculations, they must be reduced to what they would be if observed from the ship's place at the instant under consideration. A simple proportion from the data in the Nautical Almanac will enable us to do this; and the process is called "correcting" the declination, right ascension, etc.

Course.—The course is the direction in which a ship sails from one place to another, this direction being referred to the meridian, which lies truly north and south, or to the position of the magnetic needle by which the ship is steered. The former is distinguished as the *True Course*, the latter as the *Compass Course.* The course is reckoned from north towards east and west when the ship's head is less than eight points from the north; and from south towards east and west when the ship's head is less than eight points from south.

The *Course Steered* is also distinguished from the *Course Made Good*, the former being the angle between the meridian and the ship's "fore-and-aft line", the latter, the angle between the meridian and the ship's real track on the surface of the sphere, indicated by her "wake" in the water. Having given two places, and hence the true course from one to the other, the course to be steered by compass in making the voyage is deduced by the application of "variation" and "deviation." And conversely in "the day's work" the compass course steered is reduced to the true course made good by the application of the corrections "variation", "deviation", and "leeway". For figures and explanations, see **Rhumb Sailing, Fundamental Definitions.**

In rhumb sailing, the course is constant and is *the common angle which the track makes with the meridians lying between the place left and the place sought.* It is reckoned from the north point, towards the east and west, when the ship's head is less than eight points from the north; and similarly for the south point. In great-circle sailing, the course is being constantly changed.

Course and Distance.—Problem in geo-navigation. *To find the course and distance between two places of known latitude and longitude.* Two general methods of solution.

1. By "meridional parts"; from the formulæ—

$$(a).\ \text{Tan Course} = \frac{\text{Diff. long.}}{\text{Mer. diff. lat.}}$$

$$\therefore \text{L tan } \textit{course} - 10 = \text{log diff. long.} - \text{log mer. diff. lat.}$$

$$(b).\ \text{Distance} = \text{True diff. lat.} \times \text{sec course.}$$

$$\therefore \text{log } \textit{dist.} = \text{log true diff. lat.} + \text{L sec course} - 10.$$

2. By "middle latitude"; from the formulæ—

$$(a).\ \text{Tan Course} = \frac{\text{Dep.}}{\text{True diff. lat.}}$$

$$= \frac{\text{Diff. long.} \times \text{cos mid. lat.}}{\text{True diff. lat.}} \text{(nearly)}$$

$$\therefore \text{L tan } \textit{course} = \text{log diff. long.} + \text{L cos mid. lat.} - \text{log true diff. lat.}$$

$$(b).\ \text{Distance} = \text{True diff. lat.} \times \text{sec course.}$$

$$\therefore \text{log } \textit{dist.} = \text{log true diff. lat.} + \text{L sec course} - 10.$$

In the case of parallel sailing the *course* is due east and west; and the distance is found from the formula—

$$\text{Distance} = \text{Diff. long.} \times \text{cos lat.}$$

$$\therefore \text{log } \textit{dist.} = \text{log diff. long.} + \text{L cos lat.} - 10.$$

The *shortest* distance, and the varying courses to follow this shortest distance, may be found by the rules of great-circle sailing.

Course and Distance, Current.—The course and distance which is equivalent to the effect of the drift and set of the current in which a ship is sailing.—See **Current.**

Course and Distance, Departure.—The course and distance which a ship is supposed to have made from a landmark known in longitude and latitude to the spot from which she actually commences her voyage.—See **Departure.**

Crepusculum (L. *crĕpĕra*, "doubtful"; *lux*, "light").—A small circle parallel to the horizon, at about 18° below it. The sun is between this parallel and the horizon during the continuance of twilight.—See **Illumination.**

Cross Bearings.—The bearings of two or more objects taken from the same place, and therefore intersecting or "crossing" each other at the station of the observer.—See **Bearings.**

Cross Staff.—An old simple instrument for taking altitudes and distances at sea. It consisted of a straight square graduated staff and two transoms (each with square socket) sliding on it. The arms of these cross pieces or vanes were of different lengths: the ten-cross vane belonged to the side of the staff which was graduated towards the eye end up to 10°; the thirty-cross vane belonged to the side where the graduations were from 10° to 30°; the sixty-cross vane to that where they were from 30° to 60°; the ninety-cross vane where they were from 60° to 90°. The graduations were "the natural co-tangents of half-arches, the half cross being radius." This instrument was also called the *Fore Staff* and *Jacob's Staff*.

Cross-Wires.—Spider-wires placed in the focus of the object-glass of an astronomical telescope. In this position they become visible by stopping pencils of rays, which there converge to points. In this focus, also, the image of a heavenly body as it passes over the field of view is simultaneously seen, and its place is noted by referring it to the cross-wires.

Crossed Observations ("Observations croiseés", Borda).—In using Borda's repeating reflecting circle a series of pairs of observations is taken—the first of each pair with the instrument held in the direct position, the second with it reversed. The moving vernier thus passes over double the angle to be measured, index error being eliminated. The directions of the moving reflector in the two observations *cross* each other, passing between them through the position of parallelism with the fixed reflector.—See **Circle, Borda's.**

Crux (L. "The Cross").—A constellation which, together with Centaurus, constitutes a bright group in the southern hemisphere pointed to by the line joining Arcturus and Spica. α^1 *Crucis*, mag. 1; 1882, R.A. $12^h\ 20^m$, Dec. – 62° 27′.

Culminations (L. *culmen*, "the top", "ridge").—The heavenly bodies in their diurnal revolution, when they attain their greatest and their le altitude above the horizon, are said to culminate; this happens when they cross the meridian. All those bodies which are within the circle of perpetual apparition visibly come to the meridian twice in every diurnal revolution, once *above* and once *below* the elevated pole. These are respectively called their *Upper* and *Lower Culminations.* Other bodies which show themselves culminate but once.

Cumulus (L. "a heap").—The "Heap-Cloud", one of the primary modifications of cloud.—See **Cloud.**

Cumulo-stratus.—One of the combined modifications of cloud.—See **Cloud.**

Cumulo-cirro-stratus.—The Nimbus or "Rain-Cloud", one of the combined modifications of cloud.—See **Cloud.**

Current (L. *currĕre,* "to run").—A running body of water, the term being specially applied to a stream which flows through the midst of other water. A current is named after the point *towards* which it sets, whereas a wind is named after the point *from* which it blows. This is natural; for as the importance of the wind depends in a great measure on what it brings us—storm, rain, cold, or heat—so a current directs the mind to the quarter to which it is unconsciously carrying us. As with the wind, so with the current, there are two things to be noted—its *direction,* and its *intensity* or force; the technical terms for the measure of these being the "set" and the "rate." If a definite interval is contemplated, the time multiplied by the rate will give the distance due to the current, technically called the "drift." Thus, in current sailing, the *set* and *drift* are used in speaking of the current, as the *course* and *distance* are in speaking of the ship.

Currents are frequently divided into two classes, *stream* and *drift* currents. Drift-currents result from the action of the wind on the surface of the water; and therefore change with periodic winds. A stream-current is frequently produced by a drift-current being deflected by a barrier or obstruction, such as a line of coast or a reef.

It is a common practice to ascribe the difference in a ship's positions, that estimated by dead reckoning and that given by astronomical observations, entirely to the effect of current. This is irrational and misleading; for currents may be only one among many causes of the discrepancy. The habit has the vicious effect of causing a neglect of other sources of danger, such as great and rapid changes in the variation and unexpected alterations in the deviation.

Current Charts.—A Mercator's chart with the currents marked upon it will afford the navigator much assistance in making passages. An admirable one is contained in "Wind and Current Charts for Pacific, Atlantic, and Indian Oceans", published by the Hydrographic Office in 1872. Wavy lines and arrows are used to indicate the general direction of the current, and its minimum and maximum rates are attached in figures. A supplementary chart is given for that part of the Indian and China seas where a change in the Monsoon brings about a corresponding change in the set and drift.

Current Course and Distance.—The *set* and *drift* of a current treated as a course and distance in the day's work. The current is known beforehand from charts and sailing directions. It must be carefully noted whether the *true* or *magnetic* set is thus given, in order that the current course may be corrected if necessary.

Current Sailing.—When a ship is sailing through a sea in which there is a current, the effect of this current will be to set her in a certain direction and drift her at a certain rate. The consequent change in her position may be found by considering the *set* and *drift* as a course and distance, and which are called the *current course and distance.* The motion due to the action of the current goes on simultaneously with the sailing of the ship over a given distance on her prescribed course; but the two may be treated separately, and a traverse worked to obtain the combined result. Current sailing is thus reduced to a case of *traverse sailing.*—See **Sailings.**

Curvature (L. *curvatura*, "a bending").—The amount of bending of a curve from its tangent at any point. As the curvature of the circle is uniform, it is used as the measure of the curvature of other curves. The circle osculating (*i.e.* "kissing") a curve at a given point is called *the circle of curvature*. Again in the circle, the deflection from the tangent corresponding to a unit arc is inversely proportional to the radius; hence the reciprocal of the radius of a circle is the measure of its curvature, and the radius of the circle of curvature (*radius of curvature*) consequently defines the curvature of a curve. The curvature of a surface at any point is determined by that of the plane sections through the point. The above is important in connection with the figure of the earth.—See **Mile, Geographical.**

Cyclones (Gk. κύκλος, "a circle").—Rotatory storms or whirlwinds. The term, though generally applicable to all winds having a circular motion, is used specially for those of the Indian Ocean.—See **Storms, Law of.**

Cygnus (L. "The Swan").—A constellation between Lyra and Pegasus. The principal star, *α Cygni* (called also *Deneb*), may be found also by joining γ and *β Pegasi* and producing it to about twice its length. Mag. 2.1; 1882, R.A. $20^h\ 37^m$, Dec. + 44° 52′.

D.

d.—Among the letters used to register the state of the weather in the log-book, **d** denotes "*Drizzling Rain*".

Data (L. from *dare*, "to give").—Things given or admitted. In problems the *data* are the known quantities from which are to be found the quantities sought,—the *quæsita* (L. from *quærĕre*, "to seek").

Date, Astronomical and Civil.—The term "date" refers both to the day of the month and the hour of the day. The astronomical day begins twelve hours later than the civil day of the same name, the astronomical date being reckoned from noon, the civil date from the preceding midnight. The astronomical date runs through twenty-four hours; the civil date is kept in hours A.M. ("ante meridiem") and hours P.M. ("post meridiem"), twelve of each. By bearing these points in mind, one date may be easily reduced to the other, an operation constantly required in the problems of navigation.

Date, Greenwich.—The day and time (reckoned astronomically) at Greenwich corresponding to a given day and time elsewhere. It is necessary to find the Greenwich date before the information contained in the "Nautical Almanac" can be made available, because all the elements there tabulated are given for time at the meridian of Greenwich. It is deduced from the *ship date* by applying the longitude in time.

Day.—Generally, the time occupied by a rotation of the earth on her axis, as indicated to a spectator on the earth itself by the corresponding apparent revolution of the celestial concave. But more particularly, some point (which may be fixed or have a proper motion of its own) must be taken to mark its commencement and period, which we call the "point of definition," and the choice gives rise to a distinction of several kinds of days, which differ from each other slightly in length. (1) If the first point of Aries (to which the positions of all the stars are referred) be taken as the point of definition, we have what is called a *Sidereal Day;* (2) If the *actual sun's* centre be taken as the point of definition, we have the *Apparent Solar Day*; (3) If the centre of the fictitious *mean sun* be taken as the point of definition, we have the *Mean Solar Day*; (4) If the moon's centre be taken as the point of definition, we have a *Lunar Day*. These are all included under the term *Astronomical Day*, as distinguished from the *Civil Day* and the *Nautical Day*. The scientific term "Day" is never used in the sense of *day* as opposed to *night*.

Day, Astronomical.—The day used by astronomers to which to refer their observations, being distinguished from the *Civil* day which regulates the ordinary business of life. The astronomical day begins at noon and ends at noon, its hours being reckoned from 0^h to 24^h; the civil day begins at midnight and ends at midnight, its hours being reckoned through twice twelve. The astronomical is later than the civil day by twelve hours. The cause of this inconvenient difference in the modes of reckoning is, that astronomers carry on their observations chiefly at night, and if they, therefore, adopted the civil method of reckoning, they would have to change the date at midnight, the former and latter portions of every night's observations belonging to two differently numbered civil days of the month. It has, however, been questioned whether this inconvenience would be as great as that resulting from the present neglect of uniformity in reckoning time. According to the point of definition chosen [Day], the Astronomical Day is either a *Sidereal Day*, an *Apparent Solar Day*, a *Mean Solar Day*, or a *Lunar Day*; the term, when used alone, is usually understood to refer to the "*Mean Solar Day*". Reckoning in mean solar time, which is the same as civil time, a mean solar day is 24^h, a sidereal day 23^h 56^m $4{\cdot}09^s$, and an average lunar day 24^h 54^m.

Day, Sidereal.—The interval between two successive transits of the first point of Aries over the same meridian, the first point of Aries being the origin to which the positions of all stars are referred. This is called a *sidereal* day, although not strictly determined by the stars; but the very slow motion of the first point of Aries, relatively to the stars, makes this day practically the same as if a fixed star had been taken, for if two clocks be set, the one on the first point of Aries, the other on the fixed star, so as always to mark 0^h 0^m 0^s when the *point* or the *star* respectively comes to the meridian, the difference of the two clocks would only be about 3^s in a whole year. The length of the sidereal day in mean solar time (which is the same as civil time) is 23^h 56^m $4{\cdot}09^s$, the ratio between it and the mean solar day being as 1 to 1·00273791. The sidereal day is divided into twenty-four sidereal hours, and these are again subdivided into minutes and seconds.

Day, Solar.—The interval between two successive transits of the sun's centre over the same meridian. The *Apparent Solar Day* varies in length in consequence of the variable motion of the sun in the ecliptic and the inclination of the ecliptic to the equator; hence the necessity of inventing a uniform measure of time—the *Mean Solar Day.*

Day, Apparent Solar.—The interval between two successive transits of the actual sun's centre over the same meridian; it begins when that point is on the meridian. The apparent solar day is variable in length from two causes: first, the sun does not move uniformly in the ecliptic—its apparent path sometimes describing an arc of 57′, and at other times an arc of 61′ in a day; secondly, the ecliptic twice crosses the equinoctial—the great circle whose plane is perpendicular to the axis of rotation—and hence is inclined differently to it in its different parts; at the points of intersection the inclination is about 23° 27′, at two other limiting points they are parallel. A uniform measure of time is obtained by the invention of the *Mean Solar Day.*

Day, Mean Solar.—The interval between two successive transits of the *mean sun* over the same meridian; it begins when the mean sun is on the meridian. This fictitious body is conceived to move in the equinoctial with the mean motion of the actual sun in the ecliptic. The length of the mean solar day is the average length of the *apparent solar days* for the space of a solar year.

Day, Civil.—The day used for the ordinary purposes of life. The motion of the sun in the heavens, bringing the alternations of light and darkness, determines generally our social arrangements, and time being kept by mechanism, the day must be of invariable length. Hence the civil is of the same length as the mean solar day. It differs, however, from the astronomical mean solar day in the following points. The astronomical day begins at noon and ends at noon, its hours being reckoned from 0^h to 24^h; the civil day begins at midnight, and its hours are reckoned through twice twelve, from midnight to noon (ante meridiem, A.M.), and then from noon to midnight (post meridiem, P.M.). The commencement of the astronomical day is placed twelve hours later than that of the civil day.

Day, Nautical.—In the Royal Navy the Nautical Day is the same in every respect, and divided in the same manner, as the Civil Day on shore. Thus a page of the log-book is ruled so as to commence and end with midnight, and is divided into two parts by noon. As the reckoning, however, is made up to noon each day, for convenience the log-board, or page of the rough deck-log, was sometimes arranged so as to begin and end with noon. This is still the custom in the Merchant Service, even in the permanent log-book; the nautical day is (like the astronomical) made to begin at noon, and the hours are carried on to twelve at midnight, and thence, commencing afresh, to twelve the next noon. Hence the remark which is usually found in the last page of the harbour-log—"This day contains twelve hours to commence the sea-log." It would be well if the Merchant Service would uniformly follow the example of the Royal Navy, and adopt civil time for civil purposes, at sea as well as in harbour.

Day, Circumnavigator's.—A ship sailing westward runs away from the sun in his diurnal course, and, when she has circumnavigated the globe, the sun will evidently have crossed her meridian once less frequently than if she had remained stationary. On the contrary, a ship sailing eastward meets the sun in his diurnal course, and, when she has circumnavigated the globe, the sun will evidently have crossed her meridian once more frequently than if she had remained stationary. Hence a westwardly circumnavigator loses a day in his reckoning, an eastwardly circumnavigator gains a day. The alteration of the date, by inserting a day or leaving out one in the ship's log-book, should be made on crossing the meridian of 180°.

Day, Intercalary.—The day that is intercalated or inserted in the calendar in leap-year to make up for the odd hours, minutes, and seconds of the tropical year which have been left out in making the civil year to consist of 365 integer days.—See **Calendar.**

Day's Work.—The work of computation required in navigating a ship for every twenty-four hours. The term is generally restricted to the dead reckoning. At each noon the *true course and distance made good*, the *latitude and longitude*, and the *compass-bearing and distance* of the point which is to regulate the ship's course during the next twenty-four hours, are wanted. The data for this work are the latitude and longitude at the preceding noon, the compass courses and distances run on each course during the last twenty-four hours, the variation of the compass, the deviation of the compass for the various directions of the ship's head, particulars of the direction and force of the wind with the consequent leeway, and the set and drift of the current if any. The term "Day's Work" may, however, be understood to comprise *all* the computation which the navigator regularly makes every day, and the results of which he inserts in the log-book.

Dead Reckoning.—Referred to by the initials D. R. The account kept of the ship's place from results obtained by the methods of geo-navigation only, as distinguished from the account deduced from astronomical observation. Dead reckoning thus takes cognisance of *Bearings*, *Soundings*, and *Loggings*. In practice the methods of geo-navigation and celo-navigation are combined; and in working the dead reckoning it is usual to find the latitude at noon on any day, by applying the difference of latitude made good by the ship in the preceding twenty-four hours, to the latitude by observation (when an observation has been obtained) of the preceding noon. The longitude, on the other hand, is often more reliably deduced by applying the difference of longitude made good to the longitude by dead reckoning of the preceding noon, unless the chronometers can be thoroughly relied upon, and several observations concur in giving a different result from the dead reckoning. In short, the most correct place possible of the ship on the preceding noon, whether the result of dead reckoning or of observation, or of a combination of the two, is used as the latitude from and longitude from, in working the dead reckoning for the day in question.

Decamètre (Gk. *δέκα*, "ten"; Fr. *mètre*).—A French measure of length, consisting of ten mètres, and equal to 393·71 English inches.

Decimètre (L. *decĭma*, a "tenth"; Fr. *mètre*).—A French measure of length; a tenth part of the mètre, and equal to 3·937 English inches.

Declination of a Heavenly Body (L. *declinatio*, "a leaning", a deviation in a lateral direction).—The angular distance of the body from the equinoctial. It is measured by the arc of an ordinate circle secondary to the equinoctial, which is intercepted between the equinoctial and the place of the body, or by the corresponding angle at the centre of the sphere. Declinations are reckoned from 0 to 90° North (N.) and South (S.) to the poles. It is often convenient to regard them as positive (+) or negative (−), according as they and the elevated pole are of the same or different names. In the List of Fixed Stars in the "Nautical Almanac", North declinations are designated positive (+) and South declinations negative (−). The complement of the declination is the *polar distance.* Right ascension and declination are the equinoctial co-ordinates for defining the positions of points on the celestial concave and indicating their positions relatively to each other.—See **Co-ordinates for the Celestial Sphere.**

Declination, Circles of.—Great circles of the celestial concave perpendicular to the equinoctial; and so called because the ordinate "declination" is measured upon them. When polar co-ordinates is the method contemplated, this system of circles is called "*Hour Circles*" and "*Circles of Right Ascension*", as marking out all points that have the same hour angle and the same right ascension.

Declination, Parallels of.—Lesser circles of the celestial concave parallel to the equinoctial. They mark all the points of the heavens which have the same declination. Compare "Parallels of Latitude," "Parallels of Altitude."

Declination of the Compass Needle.—A term sometimes used by scientific men for the "*Magnetic Variation*" of the needle, and found in that sense in the instructions given by the Council of the Royal Society to Captain Sir J. C. Ross, on his expedition to the antarctic regions. Raper strongly protests against the term as introducing confusion into the vocabulary of practical seamen.—See **Magnetic Needle.**

Deep Sea Lead.—The instrument used for sounding in deep water.—See **Sounding.**

Definitions.—A definition is a description in which two points must be attended to: First, it must exclude everything but what is under consideration; and Secondly, one essential property only must be mentioned—others which can be deduced from this are superfluous. Thus we want a definition of the Celestial Meridian. If we say, "The Celestial Meridian is a great circle of the celestial concave which passes through the zenith"; this is true, but it includes every other vertical circle, and therefore is not a definition of the meridian. Again, if we say, "The Celestial Meridian is a vertical circle passing through the poles and the north and south points"; the whole of this is true, but the mention of all these properties is superfluous, and therefore to be avoided. Any of the following descriptions, however, is a correct definition, and one is to be preferred to the others only on account of its relation to and uniformity with the other definitions in the system we adopt: "The great circle of the celestial concave passing through the elevated pole and the zenith"; "The hour-circle passing through the zenith"; "The verti circle passing through the elevated poles"; "The circle of azimuth passing through the north or south point."

Degree (L. *gradus*, "a step"; Fr. *degré*).—The angle subtended at the centre of a circle by an arc equal to the 360th part of the circumference. A degree is subdivided into 60 minutes, and each minute into 60 seconds. As these are also the subdivisions of periods of time—the hour and minute—it seems probable that the division of the circle into the number 360 had reference to the space described by the sun in one day, in performing his annual revolution. The round number 360 was doubtless adopted for convenience as containing a great number of divisors; but the origin of the arrangement is perpetuated in the Chinese system where the circle continues to be divided into 365¼ degrees, one such space being described by the sun daily.

Degree of Latitude.—A degree of latitude on the earth's surface has been defined to be the distance an observer must advance along the meridian, in order to experience a change of one degree in the elevation of the pole. A comparison of the measured lengths of the degrees of the meridian, at different latitudes, furnishes the means of deducing the true figure of the earth.

Degrees of Longitude.—A caution is necessary against calling the minute of a degree of longitude a mile. The length of a minute of a degree of longitude varies in different latitudes, whereas a mile is a measure of invariable length.

Degree of Dependence.—The practical aspect of the *limit of probable error* in the computations of the navigator. All the elements which form the data of his problems are more or less uncertain; some of them have to be ascertained more accurately than others, and, under certain circumstances, a slight error in an observed element produces a much greater effect in the final computed result, than under other circumstances.

The knowledge of the degree of dependence in each case is indispensable in forming a right judgment of the area within which we are *sure* the true place of the ship lies; the principle should also regulate the amount of labour to be bestowed on the work of different parts of the computation.

Deneb.—An Arabic word signifying the tail. It is used to designate a bright star in the tail of some of the constellations. Thus *α Cygni* is called *Deneb; β Leonis* is called also *Denebola,* or sometimes simply *Deneb;* there is also *Deneb Algedi* in Capricornus. It were well if the word fell into disuse.

Departure.—If the rhumb-line be drawn between two places on the earth's surface, and points be taken on it indefinitely near to each other, the departure is the sum of the indefinitely small arcs of the parallels of latitude drawn through them intercepted between each of the points and the meridian passing through the adjacent one. It is the distance in nautical miles made good by a ship due east or due west, and is marked east (E.) or west (W.) according as it is made good towards the east or towards the west. In the former case it is also called "*Easting,*" in the latter "*Westing.*" When the two places are on the same parallel, the departure is identical with the distance. When the places do not differ much in latitude, and are on the same side of the equator, an approximation to the departure is found in the arc of the parallel of middle latitude included between the meridians of the two places. It must be borne in mind that the departure is expressed in *miles,* and not, like the longitude, in *arc.* The departure is connected with the distance and course by the relation, Departure = Distance × Sin. Course. — See **Rhumb Sailing, Fundamental Definitions,** and **Fundamental Propositions.**

Departure Course and Distance.—The course and distance a ship would have made from a known spot to arrive at the place whence she departs on a voyage. The ship's actual position is only known by bearing and distance from a known landmark. The latitude and longitude of this landmark are given; and thence, by supposing the ship to have sailed, on a course opposite to the bearing of the object, through the distance between that object and her starting-point, the latitude and longitude of this latter place is also found. On commencing a voyage we thus get a determinate starting-point from whence to reckon our subsequent courses and distances. In correcting the departure course for the deviation of the compass, we must bear in mind that the ship's head (on which the amount of deviation depends) is not necessarily in the same direction with the course. She may be "lying to," or riding at anchor, and swinging to any point of the compass when the bearing is taken.

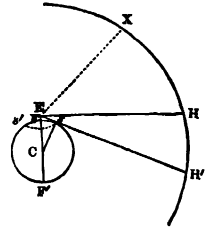
Departure, Taking a.—The process of determining the place of the ship preparatory to departing on a voyage. This is done by referring it to some other position of known latitude and longitude. A fixed and conspicuous object is determined on, and the *direction* in which the ship lies from this, and her *distance* from it, are found.

I. *Without the help of the chart.*—1. The *direction* the ship holds with reference to the object is furnished at once by taking with the compass a bearing of the object from the ship. 2. To determine the *distance*—(1) When not very great, the distance may be estimated with the eye with sufficient accuracy. (2) When the ship's path lies across the line of direction of the object, the distance may be found from two bearings of the object and the run of the ship in the interval of time between taking them. (3) Sometimes the distance may be measured by the velocity of sound. (4) When the object of departure is the summit of high land of known elevation, its distance may be easily found, either when the object is seen on the sea-horizon or above it. In case the elevation of such land is not known, the distance may be found, while standing directly towards or from it, by means of two altitudes and the run in the interval of time between observing them.

II. *With a chart* a departure may be taken by any of the following methods:—(1) By cross-bearings. The bearings of two points of land (with a difference of bearing of as nearly 90° as possible) are observed, and the lines of bearing laid down on the chart. Their intersection gives the place of the ship. (2) By two angles between three objects; a method used when considerable accuracy is required, as in recovering a lost anchor, verifying soundings, etc. (3) By the soundings; when the depth of water is not very great and varies sensibly with the distance of the object set. (4) The line of bearing of a single object may be combined with another line which crosses it nearly at right angles, and on which it is also known that the ship lies. Such a line also may be obtained by Sumner's method. If the latitude of a ship is known when the object bears N. and S., her position is determined; or, if her longitude is to be depended on when the object bears E. and W., or nearly so, her position may be laid down. Combinations of this kind would be used in cases when the bearing of one object only (as a low point of land) can be taken and there is no other means of determining the distance.

Depression, Angle of.—When a spectator is looking down upon an object, the angle of depression is the angle through which the object appears depressed below the horizontal plane drawn through his eye. We speak of the "Angle of Depression" or the "Angle of Elevation," according to the relative position of the spectator and the object.

Depression or Dip of the Sea-Horizon.—The angle through which the sea-horizon is depressed in consequence of the elevation of the eye of the spectator above the surface of the earth. The visible horizon may be regarded as the intersection with the celestial concave of a cone whose vertex is the eye, and which touches the earth's surface in a small circle—the sea-horizon [Horizon]. If the eye be situated actually *on* the surface, this cone becomes a plane, and the sea-horizon



a point; and the greater the elevation of the eye, the greater evidently will be the extent of the sea-horizon. Thus, as the eye becomes elevated the sea-horizon becomes "depressed" in proportion. Let E be the place of the spectator's eye at an elevation EF above the earth's surface, F being vertically under him. Then E is the centre of the celestial concave. Draw the horizontal EH through E, meeting the celestial concave in H; and through E also draw the tangent E*s*H′, meeting the celestial concave in H′. Then the angle HEH′ is the depression of the horizon for the height FE. To show how the dip is calculated—If *e* be the elevation of E (= FE), and R the radius of the earth (= C*s*); then dip = HEH′ = 90° − *s*EC = EC*s*. $\therefore$

$$\text{Tan. dip} = \text{tan. EC}s = \frac{\text{E}s}{\text{C}s} = (\text{by Euc. iii. } 36)\,\frac{\sqrt{\text{EF} \times \text{EF}'}}{\text{C}s} = \frac{\sqrt{e\,(e + 2\,\text{R})}}{\text{R}}$$

$$= \frac{\sqrt{2\,e\,.\,\text{R} + e^2}}{\text{R}} = \sqrt{\frac{2\,e}{\text{R}}}$$ nearly. A table called "Dip of the Sea-Horizon" is inserted in all nautical tables, calculated generally up to 300 feet elevation, that being the limit within which all observations are taken at sea. An accidental relation furnishes us with an easily remembered rule for finding it approximately:—The dip in minutes is the square root of the height in feet. The dip is one of the "corrections" that has to be applied to the observed altitude of heavenly bodies taken at sea. The observer on the deck of the ship brings the image of the body (as X) down to his visible horizon. Thus the observed altitude (as H′X) is too great, and has to be diminished by the dip (HH′) to obtain what it would have been if observed from the surface of the earth (HX). The dip gives the distance of the visible horizon, for the arc F*s* is measured by the angle EC*s* = 90 − CE*s* = HEH′.

Depression or Dip of a Shore-Horizon.—Sometimes, when the distant sea-horizon is hidden by the intervention of land, an altitude has to be observed from the water-line on the beach. The distance of this "shore-horizon" may be estimated nearly; it is always less than the distance of the sea-horizon. The dip for the shore-horizon is greater than the dip for the sea-horizon. It is given in a table of which the arguments are " the height of the eye" and " the distance of the shore."

Depression or Dip, Apparent and True.—The amount of the dip is affected by refraction, and according as the effect of refraction is not or is allowed for, the dip is called apparent or true. Refraction *raises* the sea-horizon, but the amount of the consequent correction cannot very accurately be determined. Inman gives it as about ·08 of the dip, independently of this correction. The apparent place of the sea-horizon is not only subject to inequalities depending upon particular states of the atmosphere, but it also varies with the relative temperatures of the sea and air. When the sea is warmer than the air the apparent dip given in the table is too small, in consequence of the sea-horizon being under these circumstances below its mean place; when the sea is colder than the air the contrary is the case. In finding, with the sextant, the altitude of any body when it is above 60°, the uncertainty to which the dip is liable may be eliminated by observing the altitude from the two opposite points of the horizon.

Deviation (L. *de*, " from" ; *via*, " way").—Turning aside from the way or the right line. This term is used for the deflection of the compass needle from the magnetic meridian caused by the attraction of the iron on board the ship.—[**Compass.**] It is sometimes qualified as the " *Local Deviation.*" Such qualification would be appropriate and necessary if there were a deviation, resulting from any other cause, from which to distinguish it. Raper, who invariably uses it, recommends that the simple term " Deviation" should be used rather in a generic sense implying the introduction of the term *Magnetic Deviation.* Still, however, he retains the common word " Variation," but always qualifies it as " Magnetic Variation."

It is now generally agreed to confine the term " Deviation of the

Compass" exclusively to the error caused by the attraction of the iron in the ship, whether employed in her construction, in her equipment, or in her cargo. For the three sources of compass errors, see **Compass Errors.**

Diametral Plane of a Sphere.—A plane passing through its centre and dividing it into hemispheres.

Difference of Latitude.—The difference of latitude of two places on the earth's surface is the arc of a meridian intercepted between their parallels of latitude. Hence the difference of latitude of a ship for any period of a voyage is the distance she makes good in a north or south direction. This is called also her "*Northing*" or "*Southing,*" these names being indicated by their initials, N. and S. When the two places are on the same side of the equator, the difference of latitude is found by subtracting the less from the greater; when they are on the opposite sides of the equator the difference of latitude is the numerical sum of their latitudes. If, however, the latitudes reckoned north are called positive, and those reckoned south negative, then the difference of latitude is always the *algebraic difference* of the latitudes. In plane sailing the above term is sufficient in itself, but in spherical sailing the introduction of the *Meridional Difference of Latitude* makes it necessary to distinguish it as the "*True Difference of Latitude.*" It is connected with the distance and course by the relation, True diff. lat. = dist. × cos. course.—See **Rhumb Sailing, Fundamental Definitions,** and **Fundamental Propositions.**

Difference of Longitude.—The difference of longitude of two places on the earth's surface is the arc of the equator included between their meridians, or, which is the same thing, the corresponding angle at the pole. If longitudes are reckoned from the first meridian both ways, eastward and westward, then, when the two places are both in east or both in west longitude, the difference of longitude is found by subtracting the less from the greater; when one of the places is in east and the other in west longitude, the difference of longitude is the *numerical sum* of their longitudes, except when the sum is greater than 180°, in which case it must be subtracted from 360°. It is, however, advisable to reckon longitudes in one direction, westward, completely round the circumference, and then the difference of longitude is always found by subtracting the less from the greater, and taking the remainder from 360° in cases where this remainder is greater than 180°. Problems involving the difference of longitude can only be solved by the methods of spherical sailing. We have the relation,

$$\text{Diff. long.} = \text{Mer. diff. lat.} \times \text{tan. course};$$

and in the particular case of parallel sailing,

$$\text{Diff. long.} = \text{dist.} \times \text{sec. lat.}$$

—See **Rhumb Sailing, Fundamental Definitions**, and **Fundamental Propositions.**

Dip or Inclination of the Needle.—The angle which the magnetized needle, when free to move vertically, makes with the horizontal. The common term *Dip* is preferred by some to the scientific *Inclination*, because it directs the mind to that pole of the needle which is below the horizon. The dip, like the variation, undergoes a cycle of change, and has also diurnal oscillations. Its present value at London is about 68° 30′. The dip is of importance to the navigator, as it appears to regulate the local deviation of the compass. It also renders necessary an adjustment to secure the horizontality of the compass card.

$$\text{Tan. dip} = 2 \text{ tan. mag. lat.}$$

Dip of the Horizon.—See **Depression.**

Direction.—It is important in navigation to note the manner in which direction is conventionally described. The *direction of the wind* is named after the point of the compass *from* which it blows, whereas the *direction of a current*, *stream*, or *tide-wave* is named after the point of the compass *towards* which it sets or is propagated. The reason of this is, that the importance of the wind depends in a great measure upon what it brings us—storm or rain, cold or heat; and also, the direction of the wind being apparent, it can be made available in steering the course required, and hence the eye of the seaman is directed to windward. On the contrary, the direction of the current is generally only found afterwards from its effects upon the position of the ship,—carrying it towards the point to which it is setting. The mind of the seaman is, therefore, turned to the direction in which he may be unconsciously drifting to danger; and, also, it is from the point towards which he may have drifted that he has subsequently to make allowance and modify his course. A *swell* is named after the point of the compass *from* which the waves proceed, like the wind that produces them. This is, however, sometimes expressly mentioned: *e. g.* "Swell from S.E." instead of "South-easterly swell." The "land-breeze" and "sea-breeze" blow respectively *from* the land and from the sea.

Distance.—There are no fewer than four different senses in which seamen will find this word used, viz:—(1) the length of the track which a ship makes in sailing from one place to another without changing her course; (2) the length of the shortest route between two places; (3) the angle subtended at the eye between two objects; (4) the difference in time between the meridians of two places.

"**Distance.**"—In navigation this term is used in a technical sense. The "distance" between two places is the arc of the rhumb line joining them expressed in nautical miles. It is the length of the ship's track when she sails on a constant course from the place of her departure to the place of her destination. This is always the sense in which the word "distance" is understood by the navigator, when standing alone.

It is *not* the *shortest* distance; for just as on shore we speak of the distance we should have to walk from one place to the other, and not the distance as the crow flies, so on the sea we speak of the distance which we in practice sail over. With a view of guarding against ambiguity the term "*Nautical Distance*" has been introduced. On a Mercator's Chart the rhumb is represented by a straight line, but it must be borne in mind that equal parts of any such line do not represent equal distances on the earth's surface. The distance is connected with other elements by the relations:—

Dist. = departure × cosec. course;
Dist. = true diff. lat. × sec. course.

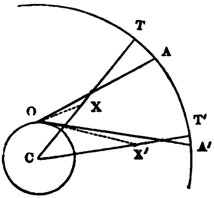
In the particular case of parallel sailing,

Dist. = diff. long. × cos. lat.

— See **Rhumb Sailing, Fundamental Definitions,** and **Fundamental Propositions.**

Distance, Shortest.—The shortest distance between two places on the earth's surface is the intercepted arc of the great circle passing through them. When we speak of the distance between two points on a plane, we mean the shortest distance, and so, in a strictly geometrical sense, on the surface of a sphere the distance would mean the shortest distance. The term *distance*, however, being used by the navigator in a technical sense for the arc of the rhumb-track between two places, when the arc of the great circle is to be indicated the word should always be qualified as the *shortest* distance. In great-circle sailing the shortest distance is the track approximated to; and on a chart on the central projection this track is represented by a straight line; but it must be borne in mind that equal parts of any such line do not represent equal distances on the earth's surface. In great-circle sailing the shortest distance is found by the solution of a spherical triangle of which two sides and the included angle are given from the known latitudes and longitudes of the two places.

Distance of Two Heavenly Bodies.—This is to be understood not as the absolute linear distance between the two bodies, but their angular distance from each other as seen from a certain point, measured by the arc of the great circle joining their projections on the celestial concave. The angular distance is taken by a navigator situated at any place on the earth's surface with a sextant, and the uncorrected result of such an observation is called the *Observed Distance.* This being cleared of "index error" and (if limbs of the bodies are observed) of "semidiameters," the observed is reduced to the *Apparent Distance.* Again, for comparison and computation, all elements have to be cleared of the effects of "refraction" and "parallax"—*i.e.* reduced to what they would be if taken by an observer looking through a uniform medium from the centre of the earth. The apparent distance is thus reduced to the *True Distance.* The two may, therefore, be thus distinguished. The apparent distance of two heavenly bodies is their angular distance as viewed through the atmosphere by a spectator on the earth's surface; the true distance is their angular distance conceived to be viewed through a uniform medium from the earth's centre. Thus, let A and T be the apparent and true places of the moon when at X; A′ and T′ the apparent and true places of the moon when at X′. Then AA′ is the apparent distance and TT′ the true distance between these two positions.



Distance, Meridian.—The difference in time between the meridians of two places.—See **Longitude, Difference of, in Time.**

Double Altitude.—A combination of two altitudes for the solution of the same problem, as finding the latitude or rating a chronometer.—See under **Altitude.**

D. R.—The initials of "*Dead Reckoning,*" which in this manner is ordinarily referred to.

Draco (L. "The Dragon").—A winding constellation, which, commencing from between Ursa Major and Ursa Minor, extends to Lyra. The two principal stars, γ and β, form a conspicuous pair, situated nearly on the line joining *α Lyræ* and *α Ursæ Majoris;* the line which joins *α Cygni* and *β Boötis* also passing near them. γ *Draconis*, also called *Rastaban*, is the nearest one to Lyra; in its diurnal course it passes over London; and if a line be drawn from it to Polaris, the pole of the ecliptic will lie near this line, at about the same distance from γ *Draconis* as that star is from Lyra. This star is of historical interest, as a change in its polar distance attracted Bradley's attention and led to the discovery of aberration. Mag. 2.3; 1882, R.A. $17^h\ 54^m$; Dec. + 51° 30′. *β Draconis*, mag. 3.2; 1882, R.A. $17^h\ 28^m$, Dec. + 52° 23′.

Drift of a Current.—The distance through which the current flows in a given time. Drift = time × rate.—See **Current.**

Drift Current.—A surface current produced by the action of the wind.

Dubhe.—The Arabic name for the bright star *α Ursæ Majoris.*—See **Ursa Major.**

Dygogram.—"Force and Angle Diogram." (A contraction for "Dynamo-gonio-gram"; δύναμις "force," γωνία "angle," γράμμα "delineation" from γράφω "to grave").—A geometrical construction representing the amount and direction of the forces which act on the compass needle. There are several distinct forms, each with its peculiar advantages; they will be found described in the "Admiralty Manual for the Deviations of the Compass."

E.

Earth, Figure of.—The earth is in form an *Oblate Spheroid.* That the general figure of the earth is spherical is proved by arguments which naturally suggest themselves to a seaman. (1) He sometimes circumnavigates it. (2) He constantly leaves and approaches high land, and meets ships in mid-ocean; the summit first appears, and finally the base. The slender topgallant-mast is seen before the heavy hull above the sea-offing. He goes aloft to look for a chase which the horizon hides from his view on deck. (3) He oftener than most men observes lunar eclipses, and is told that they are caused by the moon passing through the shadow of the earth, and he has never seen the shadow on the moon other than circular. But the earth is not a perfect sphere; it differs from a sphere in being flattened in at its polar regions and bulging out in a corresponding degree at the equatorial regions, the curvature being less as we recede from the equator to the poles. This is proved by the difference in the length of a degree of latitude measured on various parts of the meridian.

Earth, Magnitude of.—From geodesical measurements the magnitude of the earth has been determined. In Sir John Herschel's *Astronomy*, 7th edition, the following results are given. The earth is not exactly an ellipsoid of revolution; the equator itself is slightly elliptic, its longest diameter being about two miles in excess of its shortest.

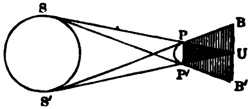
		Feet.		Miles.
Equatorial diameters	longest	41,852,864	=	7926·7
	shortest	41,843,096	=	7924·8
Polar diameter		41,707,796	=	7899·2

Hence in round numbers the equatorial circumference of the earth is a little less than 25,000 miles; and the polar compression, or difference between the equatorial and polar diameters, is about $\frac{1}{300}$th part of the diameter.

East Point of the Horizon.—The east is the cardinal point on that side of the horizon where the heavenly bodies rise. The *East* and *West Points* are the points in which the prime vertical intersects the horizon, the equinoctial also passing through them; and they are the origins from which amplitudes are reckoned. They are the poles of the celestial meridian.

Easting.—The distance expressed in nautical miles a ship makes good in an east direction; it is her *departure* when sailing eastward. Opposed to *Westing*.

Eclipse (Gk. ἔκλειψις, from ἐκλείπειν, "to leave out," "to faint away," "disappear").—The phenomenon of a celestial body disappearing from view in whole or in part, in consequence either of its passing through the shadow of another body, or from the spectator passing through the shadow of an intervening body. The sun (SS′), the source of light in our system, is much larger than any of its opaque attendant planets. Every planet, primary and secondary (as PP′), thus casts a conical shadow into space (PP′U) called the *Umbra*, within which a spectator can see no part of the sun's disc. Enveloping the umbra is a portion of another conical space (PBP′B′) called the *Penumbra*, where if a spectator be situated he could see a portion only of the sun's disc, and receive only partial sunshine, and less and less the further he enters from the exterior borders of this cone.



I. Let us consider the cases where the eclipse of a body takes place by its passing through the shadow of another body, presenting an appearance independent of the position of the spectator.

1. *Lunar Eclipses.*—A lunar eclipse takes place when the moon is in opposition, or on the opposite side of the earth from the sun (and when, therefore, it is full moon), provided she is at the same time very near one of her nodes, or the points where her orbit crosses the plane of the ecliptic. If the full moon is in the node, it will also be in the axis of the earth's shadow, and the eclipse will be *central*, possibly continuing for two hours, as the breadth of the shadow where the moon crosses it is about $2\frac{2}{3}$ the moon's diameter; when the full moon is so near the node as to be wholly immersed in the shadow, the eclipse will be *total;* and when only a part of the disc is immersed, the eclipse will be *partial*.

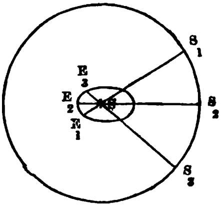
2. *Jupiter and his Satellites.*—Instead of the earth and moon, we may contemplate any other planet that has a satellite; and in doing so, we shall

notice two different kinds of eclipses. The case of Jupiter is the most important. (1) The satellite is eclipsed in the shadow of the planet, such phenomenon being to a spectator on the surface of Jupiter a lunar eclipse. (2) We observe also the shadow of the satellite passing over the disc of the planet. By a spectator on a portion of the surface of Jupiter in such a case, a solar eclipse would be experienced; but as viewed from the earth, such a phenomenon is described as a *transit of the shadow* of the satellite.

II. The second case is where a body is eclipsed by the spectator passing through the shadow of the intervening body, the appearance being different according to the position of the spectator. This occurs in *Solar Eclipses.* When the moon is in conjunction—*i.e.* in the same part of the heavens with the sun (and when, therefore, it is new moon)—the intersection of the moon's conical shadow with the earth's surface produces a black spot which sweeps over the illuminated hemisphere of the earth from west to east, and resembles in its effects a cloud carried by a west wind which hides the sun from the places nearly below it. To places over which the umbra passes, there will be a *total* eclipse; those places which the penumbra reaches will experience a *partial* eclipse. In case the umbra of the moon does not extend as far as the earth—or, in other words, when the moon's apparent diameter is less than that of the sun—a spectator below the centre of the umbra will see an *annular* eclipse, the dark disc of the moon being surrounded by a luminous "ring" of the sun's disc.

There is another class of phenomena analogous to eclipses, and which are sometimes included in the term. These are *Occultations* and *Transits.* (1) An *Occultation* is where a body is hidden from view by an apparently larger body intervening between it and the spectator. Thus the moon interposes and causes occultations of fixed stars and planets; the planets hide from view their satellites, *e.g.* Jupiter. (2) A *Transit* is where a small body passes across the disc of a larger one. Thus, we have transits of the inferior planets, Mercury and Venus, across the face of the sun; and of this character strictly speaking is an annular eclipse of the sun by the moon. We have also transits of Jupiter's satellites across his disc. Particulars of these phenomena are given in the "Nautical Almanac."

Ecliptic (Gk. *ἐκλειπτικὸς*, "pertaining to an eclipse"), so called because, an eclipse of the moon is only possible, when she is in or near the ecliptic.—The path which the sun appears to describe annually in the heavens, round the earth as centre, from west to east, in consequence of the revolution of the earth in her orbit round the sun in the same direction. The ecliptic is a great circle of the celestial concave, though the earth's actual orbit is an ellipse. To explain this: Let the figure represent the sun (S) in one of the foci of the elliptical orbit of the earth (E_1, E_2, E_3, etc.) and a section of the celestial concave by the plane of this orbit indefinitely extended (S_1, S_2, S_3, etc.). To a spectator situated on the earth at E_1 the sun will appear to be projected on the celestial concave at S_1, as the earth moves on to E_2 the sun will appear to move on to S_2, and when the earth arrives at E_3 the sun will appear at S_3; and so on until the earth, having made a complete revolution, arrives again at E_1, when the sun also, after a complete apparent revolution, will be seen again at S_1. The ecliptic is the natural equator of the heavens, and is the primitive circle in one of the systems of co-ordinates for defining points of the celestial concave and indicating their positions relatively to each other, the co-ordinates being longitude and latitude. The ecliptic is divided into twelve parts called "signs," each containing 30°, and receiving their names from constellations which were situated in them at the time the names were given. These divisions commence from the vernal equinoctial point, or first point of the sign Aries. The ecliptic must not be confused with the earth's orbit.



Elevation, Angle of.—When a spectator is looking upwards at an object, the angle of elevation is the angle through which the object appears elevated above the horizontal plane passing through his eye.

We speak of the "Angle of Elevation", or the "Angle of Depression", according to the relative positions of the spectator and object.

Ellipse (Gk. ἔλλειψις, "a falling short of").—For explanation of the derivation of the word see **Conic Sections.** The ellipse is a figure of great importance to the nautical student. Its form, in a general sense, is oval. Its exact form is given by this property: Within it are two points called *foci*, such that the sum of the distances of any point in the circumference from them is constant. Setting aside the reciprocal attraction of the earth on the sun, and the perturbations caused by the attractions of the other bodies of the system, the earth revolves in an ellipse round the sun in one of the foci. And this is the same for the orbits of the other planets. Again, the form of a meridian of the earth is an ellipse.

Emersion (L. *emergĕre*, "to come out").—The termination of an occultation, or the moment when the occulted body reappears from behind the nearer one.

Epact (Gk. ἐπάγειν, "to add in").—The number indicating the days and parts of a day "to be added" to the lunar year of twelve lunar months to make it up to the solar year. This number gives consequently the moon's age at the commencement of the calendar year. A mean lunation is $29^d\ 12^h\ 44^m$, the moon therefore describes in 365 days twelve complete lunations, and $10^d\ 15^h$ of the thirteenth; hence, on each 1st January its age is $10^d\ 15^h$, on the average, more than on the preceding 1st January, and $11^d\ 15^h$ if the preceding year was a leap year. *The Epact for the Year* is the moon's age on 1st January. Besides this there is what is distinguished as the *Epact for the Month*, which is the moon's age on the first day of the month, supposing the moon to change on 1st January at noon. These are used in questions relating to the tides, and are given in Nautical Tables.

Ephemeris—plural, **Ephemerides** (Gk. *ἐφημερὶς*, "a diary"; from *ἐπι*, prefix indicating sequence and repetition, and *ἡμέρα*, "a day").—An Astronomical Almanac is so called. In such an almanac are registered the daily positions of the sun, moon, and planets, with similar useful information respecting the other heavenly bodies; also phenomena depending upon these—as the tides. The value of all the various elements is not tabulated for *every day* at noon, but at such intervals as the nature of the several elements points out as most advantageous in each case. The term is also applied to the different tables contained in the almanac; thus the table which gives the position of the sun for every day is called "The Ephemeris of the Sun", so we have "The Ephemeris of Mars", etc. The full title of the "Nautical Almanac" is "The Nautical Almanac and Astronomical Ephemeris," and the similar work used by the Prussians is "The Ephemeris of Berlin".

Equal Altitudes.—Two equal altitudes of a heavenly body observed while it is rising on the east side and falling on the west side of the meridian.—See under **Altitudes.**

Equation (L. *æquatio*, "a making equal").—In astronomy the quantity to be added to a value of an element estimated in one way, to obtain its equivalent in another form which is required. Thus we have, *Equation of Equal Altitudes*, *Equation of Time*, *etc.*

Equation of Equal Altitudes.—See under **Altitudes.**

Equation of Second Differences.—See under **Second Differences.**

Equation of Time.—The difference between apparent and mean time. It is measured by the angle at the pole of the heavens between two hour-circles passing, the one through the apparent sun's centre, the other through the mean sun. The equation of time is so called because it enables us to reduce apparent to mean, or mean to apparent time. In consequence of the motion of the sun in the ecliptic being variable, and the ecliptic not being perpendicular to the axis of the earth's rotation, apparent time is variable [**Mean Sun**], and this fluctuation is considerable, amounting to upwards of half an hour—apparent noon sometimes taking place as much as $16\frac{1}{2}^{m}$ before mean noon, and at others as much $14\frac{1}{2}^{m}$ after. These are the greatest values of the equation of time; it vanishes altogether four times in the year—this occurring about April 15, June 15, September 1, and December 24. It is calculated and inserted in the "Nautical Almanac" for every day in the year. On p. I. of each month, the equation of time given is that to be used in deducing mean from apparent time; that on p. II. is to be used in deducing apparent from mean time. The difference in the value of the two arises from the one being that at apparent, and the other that at mean noon. As these may be separated by an interval of more than a quarter of an hour, the equation of time given in pp. I. and II. may differ by a quarter of the "Diff. for 1 hour" given in the adjoining column.

Equation of Light.—A body is seen by the light which was emitted from it at some date antecedent to that at which the light enters the eye. The interval is what is required by the undulations to traverse the space between the body and the spectator. If the object is in motion, like the sun, moon and planets, this will cause a disturbance of its place in the celestial concave which must be allowed for in reducing its apparent to its true place.

Equation, Personal, see under **Personal.**

Equator (L. *æquare*, "to divide into equal parts"):—

1. **Terrestrial Equator.**—That great circle of the earth whose plane is perpendicular to the axis of the earth, and consequently every point of which is equi-distant from the north and south poles. It divides the globe into the northern and southern hemispheres. The equator is the primitive circle in the system of co-ordinates used for defining the position of places

on the earth's surface. Origin—intersection of the equator by the first meridian; co-ordinates—longitude and latitude.

2. **Celestial Equator.**—That great circle of the celestial concave whose plane is perpendicular to the axis of the heavens. It is the great circle in which the plane of the terrestrial equator, indefinitely extended, intersects the celestial concave. The celestial equator is also called the "*Equinoctial*," and is the primitive circle in a system of co-ordinates used for defining the position of points on the celestial concave. Origin—first point of Aries; co-ordinates—right ascension and declination.

From a comparison of the above two definitions, the application of the same term "equator" to the two great circles of the earth and heavens under consideration seems appropriate; and possibly no ambiguity can occur in its use, even without the qualifying adjectives "terrestrial" and "celestial". But with students, the double use of the word often engenders a vagueness and erroneousness of conception of the things indicated, and therefore the following points must be carefully borne in mind: (1) There is not generally that connection between the circles of the earth and those of the heavens which at first sight appears. The earth rotates, while the heavens are fixed; and thus the terrestrial equator also *rotates* in its own plane, while the celestial equator must be *fixed*, as the origin of co-ordinates for the heavens is a point in it. (2) Again, the *ecliptic*, and not the equinoctial, would appear to form the *natural* "equator" of the heavens, as is indicated by the name of the co-ordinates in the system of which it is the primitive—longitude and latitude.—See **Longitude and Latitude.**

In consequence of these and other general considerations, some writers restrict the word *Equator* to siguify the *Terrestrial Equator*, and use the term *Equinoctial* when speaking of the *Celestial Equator*. This plan, if uniformly adopted, would be advantageous.

Equatorial Projection of the Sphere.—A projection of the sphere, whether orthographic, stereographic, or central, in which the primitive plane, or plane of projection, coincides with or is parallel to the "equator."

Equiangular Spiral (L. *æquus*, "equal"; *angulus*, "an angle").—A spiral is a curve which continually recedes from the centre or pole while revolving about it; the equiangular spiral on the earth's surface is the spiral which cuts the meridians at a constant angle. It is also called the "*Loxodromic Curve*," and the "*Rhumb Line*."

Equinoctial (L. *æquus*, "equal"; *nox*, "night").—That great circle of the celestial concave whose plane is perpendicular to the axis of the heavens; consequently, every point of it is equi-distant from the north and south poles. It divides the heavens into the northern and southern hemispheres. The name is derived from the following phenomena: at all the places on the earth's surface beneath this circle the nights are equal all the year round, being of the constant length of twelve hours—the sun setting at 6 P.M. and rising at 6 A.M.; and when the sun crosses the equinoctial—as he does twice in the year, at the vernal and autumnal equinoxes—the nights are of equal length all over the globe. The equinoctial is sometimes called the "*Celestial Equator*," as being the great circle of the celestial concave marked out by the plane of the terrestrial equator if indefinitely extended. It would be convenient if this compound term were altogether superseded by the simple word *Equinoctial*, and the "terrestrial equator" uniformly indicated by the simple word *Equator*. The equinoctial is the primitive circle in one of the systems of co-ordinates for defining points on the celestial concave, and indicating their positions relatively to each other. Origin—vernal equinoctial point; co-ordinates—right ascension and declination.

Equinoctial Colure.—The hour-circle which passes through the equinoctial points. In the polar co-ordinates for the celestial sphere, it is the initial position of the secondary circle.—See **Colures.**

Equinoctial Points.—The two points of the ecliptic in which it is intersected by the equinoctial. They are distinguished as the *Vernal Equinoctial Point* and the *Autumnal Equinoctial Point*, but are more generally called the *First Point of Aries* and the *First Point of Libra*, as being the commencements respectively of these signs of the ecliptic, and they are represented by their symbols ♈ and ♎. The constellations of Aries and Libra, though not now coincident in position with them, give their names to these divisions of the ecliptic, and the figure of the *Balance* (Libra) has evident reference to the equipoise of the day and night at the equinox. The first point of Aries is the origin or zero point, from which right ascensions are reckoned on the equinoctial and longitudes on the ecliptic. The equinoctial points do not, however, preserve a constant place among the stars, but travel backwards along the ecliptic—*i.e.* from east to west, or contrary to the direction in which the sun appears to move in that circle. This retrogression is extremely small, amounting to 50·1″ annually, so that a complete revolution would occupy 25,868 years. It is of great inconvenience to practical astronomers, as it renders obsolete, from time to time, their catalogues of the stars, which are referred to this shifting vernal equinoctial point as origin. Since the formation of the earliest catalogues on record the place of the first point of Aries has retrograded about 30°, altering to this extent the longitudes. The technical phrase for the phenomenon is the *Precession of the Equinoxes*,—a term derived from the fact that the epoch of the equinox every year "precedes," or is earlier than it would have been but for the retrogression of the first point of Aries.

Equinoxes (L. *æquus*, "equal"; *nox*, "night").—The two periods of the year, about 20th of March and the 22nd of September, when the sun, in his annual revolution in the ecliptic, crosses the equinoctial. At these times the days and nights are of equal length throughout the world—hence the term. The two equinoxes are distinguished as the *Vernal Equinox* and *Autumnal Equinox;* the former being that when the sun passes from the southern to the northern hemisphere, the season being "spring" in the northern hemisphere; the latter, when the sun passes from the northern to the southern hemisphere, the season being "autumn" in the northern hemisphere. These terms are relative; for what are the vernal and autumnal equinoxes for the northern, are respectively the autumnal and vernal equinoxes for the southern hemisphere. In cases where there is any danger of ambiguity or confusion, we may add the qualifying adjectives "northern" or "southern," as the case may be; thus, one date would be called the *Northern Vernal Equinox* or the *Southern Autumnal Equinox*, and the other the *Northern Autumnal Equinox* or the *Southern Vernal Equinox*. It is convenient to restrict (as we have done) the term *Equinox* to indicate a *date* or epoch of *time;* and to use the expression, *Equinoctial Point*, when we want to refer to a *position* or *place* in the ecliptic. Similarly for *Solstice* and *Solstitial Point*.

Erĭdănus (The river *Eridanus*, the Po).—A winding constellation in the southern hemisphere, containing one star of the first magnitude *α Eridani*. This star, called also *Achernar*, may be found by bisecting the line joining Fomalhaut and Canopus. Mag 1; 1882, R.A. $1^h\ 33^m$, Dec. − 57° 50′.

Errors of Instruments.—Under this head are classed sources of instrumental error which do not arise from essential *imperfections*, or for which there is no convenient or advisable means of *adjustment*. They are acknowledged, determined by experiment, and allowed for, or else eliminated by adopting certain methods of observing.—See **Instruments**; **Imperfections, Adjustments, Errors.**

Establishment of the Port.—Synonymous with "*Apparent Time of Change Tide*," or, more correctly, "*Apparent Time of Syzygy Tide*." The time of high-water at full and change of the moon, at the given port, reckoned from apparent noon. It is the actual time of high-water when the moon passes the meridian at the same time as the sun; or the interval between the time of transit of the moon and the time of high-water on full or change days. The word "establishment" expresses that this time is taken as a standard quantity, "port" being added because it is generally of importance to calculate the time of the tide for ports only. Compare the German term "*Hafenzeit*," "harbour-time." Whewell distinguishes between the *Vulgar Establishment* and the *Corrected Establishment*. The vulgar establishment may be determined roughly by observation on the day of full or change. The corrected establishment is the interval between the time of the moon's transit and the time of the tide, not *on* the day of syzygy, but *corresponding to* the day of syzygy; it may be determined by observing the intervals of the times of the moon's transit and the times of tide every day for a semi-lunation, and taking the mean of them.—See under **Tide.**

F.

f.—Of the letters used to register the state of the weather in the log-book, **f** indicates "*Fog;*" **f̣** "*Thick Fog*".

Fathom (Sax. *fæthem*).—Measure of length, six feet. Soundings are reckoned in fathoms.

Field of View.—The area within which objects are visible through a telescope or microscope when the instrument is adjusted to focus.

First Meridian.—The conventional meridian whence longitude is reckoned. In the early days of navigation, before the time of Columbus, it was not known that the direction of the compass needle goes through a cycle of change at any given place. At most places its direction deviates from that of the meridian; but it was observed, at the beginning of the sixteenth century, that it coincided with the meridian at the Isle of Ferro, one of the Canaries. This meridian was therefore fixed upon by the old geographers and navigators as the first meridian. Upon the discovery, however, of the erroneousness of their assumption, this method has been relinquished, and now different nations in general use severally the meridian of their principal observatory as their first meridian. Thus, English astronomers and geographers consider the meridian of Greenwich the first meridian, the French that of Paris, and the Prussians that of Berlin. The following are the longitudes of these the most important foreign origins, reckoned from the meridian of Greenwich westward: Ferro, 17° 58′; Paris, 357° 39′ 38″; Berlin, 346° 28′. In taking up a chart it is necessary to observe what meridian longitude is reckoned from.

First Point of Aries (L. Aries, "The Ram"). The "*Vernal Equinoctial Point*" is so called as being the commencement of the sign of the ecliptic of the same name; it is also represented by the symbol of that sign ♈.—See **Equinoctial Points.**

First Point of Cancer (L. *Cancer*, "The Crab").—The "*Summer Solstitial Point*" is so called as being the commencement of the sign of the ecliptic of the same name; it is also represented by the symbol of that sign ♋.—See **Solstitial Points.**

First Point of Capricorn (L. *Capricornus*, "The Goat").—The "*Winter Solstitial Point*" is so called as being the commencement of the sign of the ecliptic of the same name; it is also represented by the symbol of that sign ♑.—See **Solstitial Points.**

First Point of Libra (L. *Libra*, "The Balance").—The "*Autumnal Equinoctial Point*" is so called as being the commencement of the sign of the ecliptic of the same name; it is also represented by the symbol of that sign ♎.—See **Equinoctial Points.**

Fixed Stars.—See **Stars.**

Fog.—When an altitude of the sun or moon is wanted, a navigator is often disappointed by finding the horizon obscured, or the body itself shrouded in a mist or fog. If the sea-horizon, as seen from the deck, is thus unavailable, a new horizon may often be obtained by descending the ship's side, or from a boat. When the sun or moon are so indistinctly visible that the limbs cannot be detected, the hazy disc should be bisected upon the horizon.

Fomalhaut.—The proper name for the bright star *a Piscis Australis*.—See **Piscis Australis.**

Fore-staff.—An old, simple instrument for taking altitudes and distances at sea, and so called from the observer fronting the object; when using the *back-staff* his back was turned to the object.—See **Cross-staff.**

Frigid Zones (L. *frigidus*, "cold").—The two zones of the earth cut off by the polar circles. They are distinguished as the *North Frigid Zone* and the *South Frigid Zone;* the former being that in the centre of which the north pole is situated, and which is bounded by the arctic circle (about 66° 32′ N.); the latter that in the centre of which the south pole is situated, and which is bounded by the antarctic circle (about 66° 32′ S.). Reckoning from the pole to the polar circle, the breadth of each of the frigid zones is about 23° 28′. Within them, during one portion of the year (longer or shorter, according to the distance from the pole), the sun does not dip below the horizon, and during another corresponding period he does not rise above it, in the diurnal revolution. In consequence of the sun's rays striking the surface in these regions very obliquely, the temperature is exceedingly low, and hence their name.—See **Zones.**

G.

g.—Of the letters used to register the state of the weather in the log-book, **g** indicates "*Gloomy Dark Weather.*"

Galaxy.—See **Milky-way.**

Gale.—See **Wind.**

Gemma (L. "a jewel").—The proper name for the bright star α *Coronæ Borealis.*—See **Corona Borealis.**

Gemini, Constellation of (L. "The Twins").—The third constellation of the zodiac, lying between Taurus and Cancer. The two principal stars are α^2 *Geminorum* called Castor, and β *Geminorum* called Pollux. They may at once be found, as they form, with the two bright stars of Auriga, an arch round the head of Orion; as they rise, *C*apella is the uppermost star of the pair in Auriga, and *C*astor is the uppermost of the pair in Gemini, the name of the two beginning with the same letter. Or, again, a line joining Rigel and Betelgeux, and continued a little more than its own length, gives Pollux, and is also bisected by γ *Geminorum.* α^2 *Geminorum*, mag. 2.1; 1882, R.A. $7^h\ 27^m$, Dec. $+\ 32°\ 9'$. β *Geminorum*, mag. 1.2; 1882, R.A. $7^h\ 39^m$, Dec. $+\ 28°\ 19'$. γ *Geminorum*, mag. 2.3; 1882, R.A. $6^h\ 31^m$, Dec. $+\ 16°\ 30'$.

Gemini, Sign of.—The third sign of the ecliptic, including from 60° to 90° longitude. Owing to the precession of the equinoxes, the sign is at present in the constellation Taurus. The sun is in Gemini from about 21st of May to about 21st of June. Symbol ♊.

Geocentric (Gk. γῆ, "the earth"; κέντρον, "the centre").—Concentric with the earth; distinguished from *Heliocentric*, concentric with the sun. The geocentric place of an object is its position referred to a celestial concave, having the centre of the earth for its centre; the heliocentric place is its position referred to a celestial concave concentric with the sun: the former supposes the spectator to be in the centre of the earth, the latter in the centre of the sun. Thus, we have geocentric longitudes and latitudes, and heliocentric longitudes and latitudes. In the Planetary Ephemerides of the "Nautical Almanac" the positions of the bodies are given geocentrically by right ascension and declination, heliocentrically by longitude and latitude.

Geodesy (Gk. γῆ, "the earth"; δαίω, "to divide").—That part of practical geometry which relates to the determination of the magnitude and figure of the earth or any given portion of its surface. It comprehends the trigonometrical operations necessary for measuring the lengths of degrees and constructing maps.

Geography (Gk. γῆ, "the earth"; γράφειν, "to describe", "to grave"). —The science which treats of the earth in its various aspects. It is divided into different branches: (1) *Astronomical Geography*, which regards the earth as one of the bodies of the universe, and investigates its form and dimensions; (2) *Physical Geography*, which takes cognizance of its natural productions; and (3) *Political Geography*, which describes the divisions appropriated by the various communities of men. The navigator is chiefly concerned with the first two branches, but all that is ancillary to the purposes of the seaman may be classed under the term *Nautical Geography*.

Geo-navigation (Gk. γῆ, "the earth").—A term I have proposed for that branch of the science of navigation in which the place of a ship at sea is determined by referring it to some other spot on the surface of the *earth*. The other branch, in which the position of the ship is determined by finding the zenith of the place from observations of the heavenly bodies, we distinguish as *Celo-navigation*. It has been customary to apply the term "Navigation," in a limited sense, to the former of these methods; but it properly indicates the entire science, and is used in that generic sense. Laxity in the use of scientific terms is very objectionable, and the confusion arising from the same term being used in different senses very inconvenient. We therefore never use the word "Navigation" as a synonym of "Geo-navigation." Again, the term "Plane

Sailing" is sometimes loosely extended from its proper technical meaning to embrace the whole results of geo-navigation. The cause of this, perhaps, is, that apparently *plane* trigonometry only is used in the solution of its problems, it being overlooked that the construction of the table of meridional parts (of which use is made) involves the principle of the sphere. There are three methods in geo-navigation; for the spot on the earth's surface to which we refer the place of the ship may be either (1) some known landmark, (2) a determinate bottom, or (3) a previously defined place of the ship. These will be found more fully noticed under **Navigation.**

Gibbous (L. *gibbus*, "protuberant").—The phase of the moon when between half and full. The planets Mercury, Venus, and Mars present a similar appearance.

Gimbals or Gimbols, formerly **Gimmals** (L. *gemellus* "twin").—Pairs of brass hoops or rings which swing one within the other on diameters at right angles to each other, the pivots being on the inner surface of each successively larger hoop. Anything suspended in their centre retains a constant position relatively to the horizontal plane in whatever direction the framework is tilted; and hence this is the method used for hanging the mariner's compass in its place on board ship.

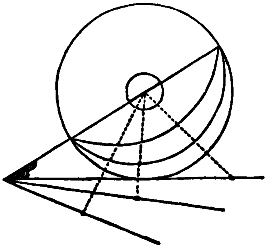
Glasses.—See **Log-glass.**

Globe (L. *globus*).—A term synonymous with the word, of Greek origin, "*sphere.*" It is generally restricted, however, to mean the *earth.* Another special application of the term is to artificial spherical representations of the earth and the heavens.

Globular Sailing.—Antiquated term for **Spherical Sailing.**

G.M.T.—The initials by which "*Greenwich Mean Time*" is referred to. —See **Time.**

Gnomonic Projection of the Sphere (Gk, γνώμων, the "style" or "index" of the sun-dial; from γνῶναι, "to mark").—The "*Central Projection*" is so called, as being that adapted for the construction of the dial. If the terrestrial sphere be imagined to be transparent, with an opaque rod for axis, then, in the diurnal revolution, this axis will throw a shadow corresponding to the hour-circles of the celestial sphere. Let these hour-circles be centrally projected on a tangent plane of the celestial sphere, and a sun-dial is formed.



Great Circle.—Great circles of the sphere are sections of its surface by planes which pass through its centre [**Circles of the Sphere**]. The great circle is to the spherical surface what the straight line is to the plane. Just as the straight line is the shortest distance between two points on a plane, so is an arc of a great circle the shortest distance between the two points on the surface of a sphere. A plane angle is formed by the meeting of two straight lines, a spherical angle is formed by the meeting of two great circles; a plane triangle is a figure contained by three straight lines, a spherical triangle is a figure contained by three arcs of great circles.

Great-Circle Sailing.—In great-circle sailing, the ship keeps on the great circle which passes through the place of departure and the place of destination. This is the shortest distance between the two places, and the ship steers for her port as if it were in sight. As the great circle, except in the cases of a meridian or the equator, does not make a constant angle with the meridians, in order to keep on it a ship must be continually changing her course. This is practically impossible, and hence what is called **Approximate Great-Circle Sailing** is more or less adopted.

In Approximate Great-Circle Sailing, several points on the arc of the great circle joining the place left and the place sought are fixed upon, and each of these made in succession by the ship sailing on the rhumb lines connecting them. The sum of the distances described on these several courses, if the points are not taken too far apart, will not differ much from the shortest distance. As the direct solution of the problem requires calculations, several plans have been devised at different times to facilitate the practice of great-circle sailing. Among these may be mentioned Towson's "Linear Index and Tables." The diagram called the "linear index" is followed by a table which gives, on inspection, all the courses on any given great circle for each 5° of difference of longitude. An instrument called "Saxby's Spherograph" is also designed to facilitate the practice of great-circle sailing. But the method lately introduced by Hugh Godfray, Esq., M.A., St. John's College, Cambridge, deserves special mention, as its beauty and simplicity will ultimately lead to its general adoption. A chart on the central projection exhibits the great circle as a straight line, and thus it is seen at once whether the track between two given places is a practicable one; hence, also, we have by inspection the point of highest latitude. An accompanying diagram then gives the different courses, and the distance to be run in each, in order to keep within one-eighth of a point to the great circle. This chart and diagram * is fully described in the "Transactions of the Cambridge Philosophical Society," vol. x., part ii.

Before Mercator's invention, great-circle sailing was commonly employed, and often in preference to rhumb sailing; but Mercator's method at once superseded it, and for the following reasons:—(1) The calculations were not so laborious, especially without the aid of logarithms, as in the great-circle method with only the direct solution; (2) The then uncertainty in the determination of a ship's longitude (chronometers not existing in their present perfection), which would be of least con-

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* Engraved by the Hydrographic Office, Admiralty. Published by J. D. Potter, Poultry, London.

sequence in rhumb sailing, for a definite rhumb line and parallel of latitude of themselves determine the position; and (3) The Mercator's chart exhibits the track of the rhumb as a straight line—one great objection to great-circle sailing being the difficulty of ascertaining whether obstacles in the shape of land or rocks lie in the path. The improvement, however, in our means of navigation, and the extension of our commerce, especially to high latitudes, where the advantages of great-circle sailing are most conspicuous, have again called attention to it. Steamers may generally take advantage of the great circle, and sailing vessels must not overlook its principles, particularly in windward sailing. Great-circle sailing must not be regarded as a substitute for rhumb sailing, but its practical utility is most apparent when treated as an auxiliary to it.—See *Nautical Magazine*, 1847, p. 288.

It is of great use to be able to project the great circle on a Mercator's chart. The following method is a simple one:—Draw the rhumb line between the two places; find the differences between the course thus obtained and each of the two terminal courses on the great circle found by calculation; on the polar side of the straight line joining the places set off the differences at each end, and from the same points draw perpendiculars to the four lines thus obtained. The intersections of those pairs of perpendiculars which make equal angles with the rhumb line will be the centres of circles of which arcs drawn between the two places will be the limits between which the required curve will lie. This curve can then be very approximately drawn by hand, taking care to make one extremity approach the sweep of that circular segment the angle of which corresponds to the great circle course at that place, and varying the curve more and more to the other extremity, so as to coincide ultimately with the sweep of the other segment, the angle of which represents the great circle course there.—See *Naval Science*, April, 1873, p. 190.

As great-circle sailing requires only the solution of a spherical triangle, it involves very little trouble each day to calculate the course on th great circle *from the point arrived at* to the port of destination, instead of trying to keep near to the great-circle passing through the original place of departure and the destination.

Greek Alphabet.—The small letters of the Greek alphabet are used to distinguish the different stars of the constellations; thus the star Dubhe is *α Ursæ Majoris*, Rigel is *β Orionis*. The navigator should not, therefore, be ignorant of these characters:—

α Alpha (a).
β Beta (b).
γ Gamma (g).
δ Delta (d).
ε Epsīlon (ĕ).
ζ Zeta (z).
η Eta (ē).
θ Theta (th).
ι Iōta (i).
κ Kappa (k).
λ Lambda (l).
μ Mu (m).
ν Nu (n).
ξ Xi (x).
ο Omīcron (ŏ).
π Pi (p).
ρ Rho (r).
σ Sigma (s).
τ Tau (t).
υ Upsīlon (u).
φ Phi (ph).
χ Chi (ch).
ψ Psi (ps).
ω Omĕga (ō).

They are also used in algebraical expressions, especially for subsidiary angles.

Greenwich Date.—The time at Greenwich corresponding to any given time at another place.—See **Date, Greenwich.**

Greenwich Date Logarithm for the Moon.—The logarithm of 720 (the number of minutes in 12 hours), diminished by the logarithm of the number of minutes in any period less than 12 hours is called the "Greenwich Date Logarithm for the Moon" for that period. These are calculated for all periods up to 12^h, at intervals of 1^m, and form a table formerly used for finding the moon's right ascension and declination for any Greenwich date between those given in the "Nautical Almanac." This table is now superfluous, since the elements are given for every hour with the variation in 10^m.—See **Logarithms, Proportional.**

Greenwich Date Logarithm for the Sun.—The logarithm of 1440 (the number of minutes in 24 hours), diminished by the logarithm of the number of minutes in any period less than 24 hours, is called the "Greenwich Date Logarithm for the Sun" for that period. These are calculated for all periods up to 24^h, at intervals of 1^m, and form a table formerly used for finding the sun's right ascension and declination for any Greenwich date between those given in the "Nautical Almanac." This table is now practically obsolete; the best means of correcting these elements is supplied by their variation in one hour being given for each day in the "Nautical Almanac."—See **Logarithms, Proportional.**

Gregorian Calendar.—The calendar as reconstituted by Gregory XIII. (Pontifex Maximus).—See **Calendar.**

Grus (L. "The Crane").—A constellation to the south of Piscis Australis; the only bright star in it is easily found by bearing S.W. of Fomalhaut. α *Gruis*, mag. 2; 1882, R.A. 22^h 1^m, Dec. — 47° 32′.

Gyration.—(Gk. γῦρος, "round").—A vertical motion, or rotation with a centripetal or centrifugal tendency. When there is a shift of wind, that shift is commonly towards the right in northern latitudes, and towards the left in southern latitudes. This has been named the *Law of Gyration (das Drehungsgesetz*, Dove).

H.

h.—Of the letters used to register the state of the weather in the logbook **h** indicates "*Hail.*" Hail usually precedes storms of rain, but rarely, if ever, follows them. It is always accompanied with electric phenomena.

Hack Watch.—A good watch with a seconds finger, used in taking observations to obviate the necessity of constantly moving the chronometer.—See **Chronometer, Observation.**

Hand-Lead.—The instrument for sounding when passing through shallow water.—See **Sounding.**

Heaving the Log.—Using the log to ascertain the rate the ship is going. —See **Log.**

Heeling Deviation.—The disturbance of the compass needle introduced by the heeling of the ship. It is commonly spoken of as the "heeling error," implying that it is an error to which the deviation (as determined when the compass is adjusted) is liable.—See **Compass, Heeling Deviation.**

Heliocentric (Gk. ἥλιος, "the sun"; κέντρον, "the centre").—Concentric with the sun; distinguished from *Geocentric*, concentric with the earth. The heliocentric place of a heavenly body is its position referred to a celestial concave concentric with the sun. Thus we have the *Heliocentric Longitude* and *Heliocentric Latitude* of a planet.—See under **Geocentric.**

Hemisphere (Gk. prefix, ἡμι, "half" = L. *semi*; *σφαῖρα*, "a sphere").—Half the sphere. Every great circle of a sphere divides it into two hemispheres; thus the equator divides the terrestrial sphere into the *northern* and *southern hemispheres.*

Hercules.—A constellation to the south of Lyra and Draco, containing one bright star. This star and *α Ophiuchi* form a pair which may be found by their being the first bright stars in a line drawn southward from the pair in Draco, *α Herculis* being the nearest to the Great Bear. Mag. var. 3.4; 1882, R.A. 17^h 9^m, Dec. + 14° 32′.

High Water.—The phase of a tide when the water attains its highest level. Its opposite is *Low Water.*—See **Tide.**

Height of the Tide.—The difference in the level of high and low water. A preferable term for this is the "*Range of the Tide.*"—See **Tide.**

Height of a Wave.—The perpendicular rise of the vertex of the wave or "crest" above the lowest part of its depression or "hollow."—See **Wave.**

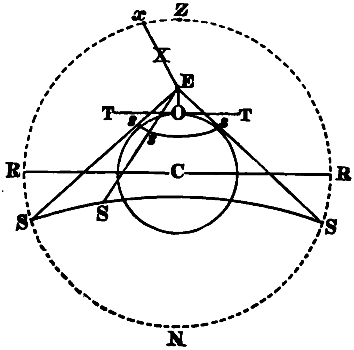
Horary Circles.—See **Hour-Circles.**

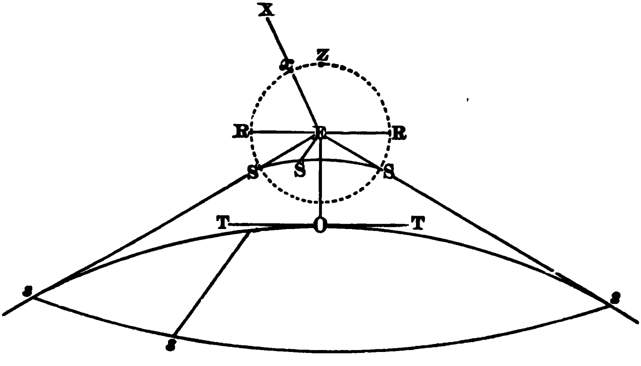
Horizon (Gk. ὁρίζων, "the boundary line"; from ὅρος, "a boundary").—The boundary circle in which the heavens and earth appear to meet. This boundary line not only thus appears to separate the surface of the earth from the celestial concave, but it divides each into two parts, the *visible* and *invisible*. The eye of a spectator is always practically more or less raised above the earth, so that his vision takes in more or less of the earth's surface, and more than a hemisphere of the celestial concave. Thus, let E be the place of a spectator's eye raised above the earth at O; it may be considered the vertex of a cone of visual rays, which are tangents to the earth's surface, marking out the terrestrial boundary of his vision *ss*, and the celestial boundary of his vision SS, these two circles appearing coincident as the boundary of the earth and sky. Their position, besides varying with the elevation of the eye of the spectator, is also still further lowered from the effects of refraction. Neglecting this, the surface of the tangent-cone to the earth, having its vertex in the eye of the spectator raised *above* the surface of the earth, defines the *Visible Horizon for that elevation*, both with respect to the earth and the heavens.

(*a*) The small circle, in which the cone touches the earth, *sss*, is the "*Terrestrial Visible Horizon*," and the visible area which it includes is but a small portion of the earth's surface. When the spectator is surrounded by the open sea, this is called the "*Sea-Horizon*" or "*Offing*."

(*b*) The cone again intersects the celestial concave in a small circle SSS, but so that more than a hemisphere of the heavens is within the spectator's field of view; this may be called the "*Celestial Visible Horizon*" *for the given elevation*.

The spectator always sees less than a hemisphere of the earth O*sss*, and always more than a hemisphere of the heavens ZSSS. A variable small circle like the sensible horizon SSS cannot serve as an axis of celestial coordinates. The required great circle RR is obtained by drawing a plane through the centre of the earth parallel to the sensible horizon tangent plane to the earth's surface at the station of the spectator (TT). This is called the *Rational Horizon* of the observer's station because it is





the plane of reference from which "reckoning" (L. *ratio*) is made for comparison and computation. It is this great circle of the sphere which is called the *Celestial Horizon*, or simply *The Horizon.* As the spectator stands on the surface of the earth the visible pole of the horizon is directly *above* his head ("zenith") and the invisible pole directly *below* his feet ("nadir"), and hence the horizon is said to divide the heavens into the *upper* and *lower* hemispheres.

Herschel ("Outlines of Astronomy" Art. 74) in explaining the above terms proceeds on the assumption of a celestial concave with a radius infinite compared with the earth's radius. The upper figure in the adjoining diagram represents this hypothesis. His definitions are in effect as follows: *Sensible Horizon,*—The plane touching the earth at the station of the observer, and extended to the celestial concave; *Rational Horizon,*—The plane through the centre of the earth drawn parallel to the tangent plane at the observer's station; *Celestial Horizon,*—The great circle in which the planes of the sensible and rational horizon (considered coincident when produced indefinitely) cut the celestial concave. We think, however, that much clearer ideas may be obtained by regarding the eye (E) as the centre of a sphere of definite radius whose use is simply to introduce spherical triangles. The lower figure in the adjoining diagram represents this hypothesis. [See **Celestial Concave.**] The Rational Horizon would in this case be a plane RR drawn through the eye E of the observer, parallel to the sensible horizon *ss* or tangent plane TT. The angle RE*s* is the *Dip of the Horizon;* and REX and *s*EX respectively the true and the apparent altitudes of the heavenly body X. If a small sphere be described, concentric with the eye (as by the dotted lines in the figure), arc RS is the dip of the horizon, Rx and S*x* the true and apparent altitudes of the body X. This way of considering the subject will enable the student to understand better the principle of the Artificial Horizon.

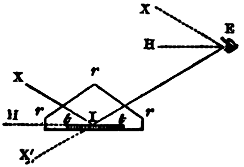
Horizon, Visible.—The boundary of our view, whether of the heavens or of the earth.

Horizon, Sea.—The small circle which bounds the view of a spectator in the open sea.

Horizon, Shore.—When the sea-horizon is hidden from view by intervening land, *the water-line on the beach* often serves the purpose of a horizon in observing altitudes.—See **Depression of Horizon.**

Horizon, Artificial.—A reflector whose surface is perfectly horizontal, used to observe altitudes on shore. Artificial horizons are of two kinds; (1) those for use on shore, and (2) those for use on board ship.

1. (*a*) The most useful form of the shore artificial horizon is a rectangular trough of quicksilver or other fluid. Quicksilver is the fluid most convenient and the best adapted for obtaining a surface which shall quickly subside after being disturbed. The trough (*tt*) is shallow and a few inches in length; it is fitted with a roof (*rrr*) formed of plates of glass with parallel surfaces, to protect the fluid from the disturbing effects of the wind. The principle is the same in all modifications of the instrument. The image of an object reflected from a horizontal surface (at I) appears as much below the horizontal line (in the direction X′) as the object itself (X) is above it, the angle of reflection being equal to the angle of incidence. Hence the angular distance between the object itself and the reflected image (XIX′) gives double the altitude (HIX or HEX). It evidently follows that no altitude can be observed in this manner which is greater than half the range of the instrument; thus with a sextant (properly so called) no altitude above 60° can be observed. For altitudes less than 15° the observation is generally impracticable. One advantage of the artificial horizon is, that when the angle shown by the instrument is halved to obtain the angle of elevation, all errors of observation are halved at the same time. There is no cor-



rection for "dip." The instrument used for observing is sometimes fixed upon a small pillar. In this artificial horizon an essential condition is the parallelism of the faces of plate-glass forming the roof. The effects of refraction may be practically eliminated by making these plates circular discs which admit of being turned in their own plane. One set of observations having been taken, the plates are turned through 180° and a new set taken, the two being used in combination; or with a common roof the error may be practically eliminated by reversing it. (*b*) A small mirror of polished metal or of darkened plate-glass is sometimes used as an artificial horizon, its horizontality being ascertained by means of a spirit-level placed upon it, and the adjustment effected by means of screws which form its stand. Such an instrument, though convenient and portable, does not give satisfactory results.

2. At sea the celestial bodies are sometimes distinctly visible when the horizon is enveloped in mist; the sea-horizon is often disturbed by haze or fog, and by moonlight is often uncertain. Hence the attempts to invent an artificial horizon adapted for use on board ship. Mr. Serson suggested to apply the principle upon which a top when spinning, tends to preserve a vertical position. A pivot carrying a mirror thus rotating would theoretically give the horizontal reflector required; but it failed in practice. Admiral Beechey's contrivance is more successful. The telescope of the sextant is fitted with a balance carrying a glass vane, one half of which is coloured blue to represent the sea-horizon, and to which the celestial object is brought down. The amount of oscillations above and below the level is indicated by divisions on the glass, the value of a division being determined by the maker. Other constructions, where the horizon is attached to the sextant, have been tried with more or less success.

Horizon-Glass.—In reflecting astronomical instruments, such as the sextant, the horizon-glass is that which is *fixed* in front of the telescope, the lower portion of it being a mirror, the upper transparent. It derives its name from the fact that in taking an altitude the "horizon" is seen by direct vision through the portion furthest from the plane of the instrument.

Horizontal.—This qualifying term has two significations which should be carefully distinguished and borne in mind. It would be a great advantage, in the interests of accuracy and simplicity, if this double use of the terms were discontinued, especially when there appears to be no necessity for it.

1. *Horizontal* is used in the sense of "parallel with the horizon", whether applied to a line or a plane. It is thus opposed to *vertical*, which describes a position at right angles or perpendicular to the horizon. Thus "the horizontal diameter of the sun" and "the vertical diameter of the sun" might appear to be phrases admitting of no ambiguity. This, however, is not the case with the former, though commonly used with this meaning in measuring it for index-error.

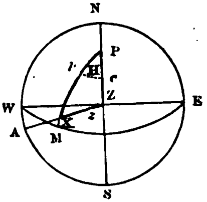
2. *Horizontal* is used to describe "the value of an element of a body when "in the horizon". Thus "the horizontal semi-diameter of the moon" is her diameter when she is in the horizon; and so in the phrase "horizontal parallax". These terms are opposed to "the semi-diameter in altitude" and "parallax in altitude". Notwithstanding their authoritative adoption, we suggest that they might advantageously be replaced by the unobjectionable terms, "horizon-semi-diameter" and "horizon-parallax". We should then escape from such an apparently paradoxical expression as "the contraction of the moon's vertical horizontal semi-diameter".

Horizontal Parallax.—The parallax of a celestial body when in the horizon of the observer; distinguished from the *Parallax in Altitude.*—See **Parallax.**

Horizontal Projection of the Sphere.—A projection of the sphere—whether orthographic, stereographic, or central—in which the primitive plane or plane of projection coincides with, or is parallel to, the "horizon." —See **Projections.**

Hour-Angles.—Generally, angles at the poles of the heavens included between different hour-circles.

Hour-Angle of a Heavenly Body.—The angle at the elevated pole included between the celestial meridian of the observer and the hour-circle passing through the body. *Time-angle* would be a more appropriate term than hour-angle, but the application of the latter, used in this general sense, is established. It is reckoned positively from the upper culmination of the body westward from 0 to 360°. The hour-angle is sometimes reckoned from the meridian in both directions—positively to the westward, and negatively to the eastward; it would be well however, if it were always reckoned in conformity with the apparent diurnal motion, just as right ascension is reckoned in conformity with the direct movements of the heavenly bodies. The hour-angle is an important element in most of the problems of celo-navigation, where it is found in connection with the zenith distance of the body z, its polar distance p, and the polar distance of the observer's zenith c (= his co-latitude). If a be the altitude of the body, δ its declination, and l the latitude of the observer; then $z = 90 - a$, $p = 90 \pm \delta$, $c = 90 - l$; and from the triangle PZX, we can find H from any of the following formulæ:—



1. $$\text{Cos.}^2 \frac{H}{2} = \frac{\sin S . \sin (S - z)}{\sin p . \sin c}$$

$$\text{Where } S = \frac{z + p + c}{2}$$

2. $$\text{Sin.}^2 \frac{H}{2} = \frac{\sin \tfrac{1}{2} (z + \overline{p \sim c}) \sin \tfrac{1}{2} (z - \overline{p \sim c})}{\sin p . \sin c}$$

3. $$\text{Hav. } H = \frac{\sqrt{\text{hav} (z + \overline{l \mp \delta}) \text{ hav} (z - \overline{l \mp \delta})}}{\cos \delta \cos l}$$

(± according as l and δ are of the same or different names. The necessity of this consideration is avoided if we retain p and c in the formula).

$$\therefore \text{ L.hav } H = \text{L.sec } \delta + \text{L.sec } l - 20$$
$$+ \tfrac{1}{2} \text{ L.hav} (z + \overline{l \mp \delta}) + \tfrac{1}{2} \text{ L.hav} (z - \overline{l \mp \delta}).$$

Hour-Angle and Polar Distance.—The polar co-ordinates for defining points of the celestial concave relatively to the position of an observer on the earth's surface. The hour-angle is measured at the elevated pole of the heavens from the celestial meridian of the observer, and is reckoned positively from the upper culmination of the point in question westward; the polar distance is measured on the hour-circle which passes through the point from the elevated pole through 180° to the depressed pole. The use of this system is to mark, at any definite moment, the relative position of a heavenly body and the zenith of the observer. The celestial meridian of the place is the initial position of the *radius vector;* it is a celestial circle which must be regarded as the projection of the terrestrial meridian and in rigid connection with it.—See **Co-ordinates for the Celestial Sphere.**

Hour-Circles, or **Horary Circles.**—These were originally circles on globes drawn through the poles 15° from each other, and thus marking intervals of hours. Now the term is used more comprehensively, and generally for all the great circles passing through the poles of the heavens, marking out the zeniths of all the places which have the same time. A more appropriate term would be time-circles. The hour-circle is regarded as the *radius vector* in a system of polar co-ordinates. This series of circles is co-axial with the "*Circles of Declination.*"

Hurricanes (*huracan*, a native American word adopted through the Spaniards).—The name by which "*Revolving Storms*" are known in the West Indies and Atlantic generally.—See **Storms.**

Hydra (Gk. *ὕδρα*, "the water-snake").—A constellation running along the south of Cancer, Leo, and Virgo. Its principal star, *α Hydræ*, called also *Cor Hydræ* and *Alphard*, may be found by continuing the line from δ and γ *Ursæ Majoris* through Regulus to about half its length; or the line joining Castor and Pollux points it out. Mag. 2; 1882, R.A. $9^h\ 22^m$, Dec. − 8° 9′.

Hydrography (Gk. ὕδωρ, "water"; γράφειν, "to describe", "represent").—The science which treats of the waters of the globe, teaching the art of constructing charts of seas and the adjacent coasts for the special use of the navigator.

Hygrometer (Gk. ὑγρός, "moist"; μέτρον, "measure").—An instrument for measuring the moisture of the atmosphere. The simplest form, and one adapted for ship use, is on Mason's principle, and consists of a combination of two thermometers, which are hung in the shade, in still air, near, but not within three inches of each other. One of these thermometers is kept dry, while the bulb of the other is kept damp by having a small strip of wetted linen or cotton rag tied loosely on, while a shred, two or three inches long, hangs down into a small holder of water, and feeds it by capillary action. The moist or wet bulb is cooled by evaporation; the moister the air the less will be the evaporation, and the drier the air the greater will be the evaporation. Thus the moist-bulb thermometer shows a temperature nearly equal to that of the dry-bulb thermometer when the atmosphere is extremely damp, giving notice of rain, fog, or dew; on the other hand, the wet-bulb thermometer shows a temperature considerably less than the other in proportion to the dryness of the atmosphere, presaging dry weather. A Barometer, Thermometer, and Hygrometer together, form a perfect *Weather-glass.* Any seaman may furnish himself with a rude indicator of the degree of moisture in the atmosphere by hanging up a bit of sea-weed.

I.

Illumination, System of Circles of.—The surface of the earth with reference to its illumination by the sun is divided into two parts—one enlightened, and the other in the shade. The corrections for parallax, refraction, and semi-diameter being made, these portions are hemispheres, and are divided from each other by a great circle. This great circle has been called *The Circle of Illumination* by most modern writers, old writers calling it *The Terminator*, from its property of bounding the verges of light and darkness. At all points on the earth's surface situated, at any given moment, on this circle, the sun is in the horizon or his altitude 0°. The line joining the centres of the sun and earth will pierce the surface of the earth at the pole of this great circle, and this point is called *The Pole of Illumination.* To a spectator situated there the sun is in the zenith, or his altitude 90°. If parallel to the circle of illumination a system of small circles be drawn, they may appropriately be called *Parallels of Illumination.* Only one of these, however, palpably marks any difference with respect to the degree of light, viz. *The Parallel of Twilight* (or *Crepusculum*), 18° on the side of the Terminator remote from its pole. But on every point of each parallel the sun has the same altitude, and hence they have been called *Parallels of Equal Altitude.* This property is the foundation of the method for finding the position of a ship commonly known as **Sumner's Method.** A similar system of great circle, pole and parallels may be connected with any other heavenly body besides the sun; *i.e.* for any star there is a great circle on the earth's surface, at every point of which, at any given moment, it will appear in the horizon, there is one point where it will be in the zenith, and a system of small circles from every point of each of which it will have the same altitude. For such a system the following terms are appropriate: *The Great Circle*, or simply *The Circle of Position; Pole of Position*, and *Parallels of Position.* I have discussed the subject with diagrams and given an historical sketch of its practical application in a paper in *Naval Science*, January, 1874, " Curves of Position for Determining the Place of a Ship at Sea."—See **Position, Parallel of.**

Immersion (L. *immergĕre*, " to plunge in ").—The commencement of an occultation, or the moment when the occulted body disappears behind the nearer one. The reappearance of the body is called its *emersion.*

Imperfections of Instruments.—In buying an instrument, such as a sextant or compass, it is important to examine its perfection in several essential points. Essential *imperfections* should lead to its rejection, as no means of *adjustment* can obviate the resulting errors, nor can these *errors* be acknowledged and allowed for or eliminated.—See under **Instruments.**

Inclination of the Ecliptic.—The angle which the ecliptic makes with the equinoctial, its value being about 23° 28′. More commonly known as the **Obliquity,** which see.

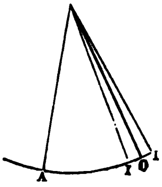
Inclination of the Needle.—The term generally used by scientific men on shore for the "*Dip*" of the Magnetic Needle. First noticed by Robert Norman in 1576. *The Inclination Needle* indicates the angle which the line of magnetic force makes with the horizon, the needle before being magnetised having been suspended at its centre of gravity so as to preserve any position.—See **Dip.**

Inclination of Ship.—As the deviation of the compass is affected by the heeling over of the ship, it becomes necessary to note, not only the direction of the ship's head, but also her inclination. Six degrees to starboard or eight degrees to port (for example) may be registered as 6° St., 8° Po. In iron-built ships the resulting correction cannot be neglected.—See **Compass, Heeling Deviation.**

Incommensurable (L. *in*, negative prefix, *com*, *cum* "with", *mensurabilis* "mensurable").—Not commensurable. Two quantities are said to be incommensurable when they have no common measure; so that when one of them is capable of being expressed in terms of a certain unit the other is not. Thus the side of a square and its diagonal are incommensurable; the diameter and the circumference of a circle are incommensurable. It is necessary that the student should grasp this idea.

Index or Characteristic of a Logarithm.—The integer part of the logarithm, whether positive or negative.—See **Logarithms.**

Index Correction.—The consequent correction that has to be applied to an observation taken with an instrument that has an index error. Let O be the zero point of the graduation of the limb, and when the mirrors are placed parallel, let I be the position of the index. Then it is evident that IO ($= e$) is the index error, and every arc, as OA, observed with the sextant must be corrected by subtracting e if I be *on*, and by adding e if I be *off*, the graduated part of the limb.—See under **Sextant.**



Index Error.—The index error of reflecting astronomical instruments, such as the sextant, is the difference between the zero point of the graduated limb and where the zero point ought to be as shown by the index when the index-glass is parallel to the horizon-glass.

Index-Glass.—In reflecting astronomical instruments, such as the sextant, the index-glass is the mirror at the centre attached to and moving with the "index-bar;" hence its name.

Inferior (L.).—An adjective often used to qualify scientific terms, indicating "below", "lower", "inner"; and opposed to *Superior*, which indicates "above", "upper", "outer". Thus we have the *inferior tide*, which occurs at any place when the moon is below the horizon; the *inferior culmination* of a circumpolar star; the *inferior planets*, whose orbits are within that of the earth; and the *inferior conjunction* of an inferior planet.

Inman's Rule.—The method of solving the problem "Latitude by Double Altitude," selected by Dr. Inman, and sometimes distinguished by his name. It is the most general method of solution, applying to the same or different heavenly bodies observed either at the same or at different times.—See **Latitude, how found.**

Inspection.—Solving a problem by inspection is the obtaining the result at once by looking into a table, the arguments of which are the data of the problem. Though few problems can be wholly solved in this manner, still the method is used in the different steps and portions of nearly every problem in navigation. The Traverse Table may be thus used to solve any right-angled triangle. For example, in the day's work, the diff. long. may be taken out by inspection; and in a Double Altitude "the run" may be found by the use of the same Table.

Instruments; Imperfections, Adjustments, Errors.—Under the head of *Imperfections of Instruments* are included actual imperfections in their construction, such as essentially impair their efficiency. It is important, when buying an instrument, to be acquainted with the points where such imperfections may be expected and the means of detecting them. Inferior instruments will thus be rejected. *Adjustments of Instruments* is a term having reference to sources of error arising from the fitting of the component parts of the instrument which are constantly liable to get out of order, and some of which have to be rearranged according to circumstances. Special machinery is provided to rectify the instrument. An observer must be acquainted with the manner of testing on all points, and the means of making the several adjustments. *Errors of Instruments* is a phrase indicating such points as are permitted to remain unadjusted in an instrument when used. They are acknowledged, determined by experiment, and "corrections" made for them. An observer constantly satisfies himself upon the error of his instrument.

Intercalary Day.—The day "intercalated" or inserted in leap years to make up for the odd hours, minutes, etc., neglected by reckoning the ordinary civil year to consist of 365 integer days.—See **Calendar.**

Interpolation.—The finding a value of an element which falls between two given values. This process is called into constant requisition in navigation. The different elements tabulated in the "Nautical Almanac" are given for particular times at Greenwich, and their value at any instant between two of these times may be found by working a proportion in the ordinary way, or by proportional logarithms. The method, however, practically adopted, in most cases, is that rendered available by the variation of the elements being now given in the "Nautical Almanac", those of the sun in 1^h, and those of the moon in 10^m. In most cases an approximation is sufficient. When extreme precision, however, is required it has to be remembered that, in general, these elements do not change uniformly, and a correction has to be applied which is called the *Equation of Second Differences.*

Iron-built Ships.—The application of iron to shipbuilding has necessitated a change in the treatment of ship's compasses.—See **Compass Deviation in Iron Ships.**

Irradiation (L. *irradiare*, "to shine upon").—The apparent enlargement of the disc of a heavenly body, caused by the vivid impression of its light on the eye. This phenomenon is perhaps best illustrated by the appearance of "the new moon in the old moon's arms", the slender bright crescent appearing to the eye to be a portion of a larger circle than the part of the disc which is visible in the shade. The effect of irradiation on the apparent diameter of the sun may amount to as much as 6″, but so small a quantity as this is of no practical importance. It may, however, be removed by observing both limbs.

Isoclinal Lines (Gk. *ἴσος*, "equal", *κλίνειν*, "to make slope").—Lines of equal magnetic dip.—See **Magnetism Charts.**

Isogonic Lines (Gk. *ἴσος*, "equal", *γωνία*, "an angle").—Lines of equal magnetic variation.—See **Magnetism Charts.**

Isodynamic Lines (Gk. ἴσος, "equal", δύναμις, "force").—Lines of equal magnetic force.—See **Magnetism Charts.**

Ivory's Rule.—A method of solving the problem "Latitude by Double Altitude" of the same body. It applies strictly only to such bodies as do not change their declination in the interval; but is also practically available in the case of the sun, by using the mean of the two polar distances; and similarly for the moon at the seasons of her greatest declination N. and S., when the change of that element is very slow. The triangles formed by the polar distances, zenith distances, and distance of the bodies, are, by drawing perpendiculars, cut up into right-angled triangles, the successive solution of which leads to the determination of the co-latitude, and hence to the latitude.—See **Latitude, how found.**

J.

Jacob's Staff.—A name sometimes given to the **Cross-staff.**

Jupiter (named after the king of the Roman gods).—The largest planet of the solar system, its diameter being about 11¼ times that of the earth, and its bulk about 1500 times greater. It revolves at about 5¼ times the distance of the earth from the sun, next in order after the numerous group of small bodies called the asteroids. It is accompanied by four moons or satellites. [See **Planets.**] The apparent angular diameter of Jupiter varies from 30″ to 46″. It is a body of the greatest importance to the navigator; for besides serving in a pre-eminent manner the ordinary purposes of bright stars (such as, by its altitude, determining the latitude and, by its lunar distances, furnishing the means of finding the longitude), the eclipses of Jupiter's satellites give an independent method of obtaining the longitude.—See **Longitude, how found.** Symbol ♃.

Journal, Ship's.—See **Log-book.**

Julian Calendar.—The Calendar as reconstituted by Julius Cæsar (Pontifex Maximus).—See **Calendar.**

K.

Keel, Even.—This phrase properly describes the condition of a ship when she draws the same depth of water forward and aft, and when she is not pitching. It is also improperly though very commonly applied to indicate that a ship is on an *even beam*. The deviation of the compass is modified by the heeling of the ship to starboard or port, and the *heeling correction* has to be applied to the results obtained on the hypothesis that the ship is on an even beam. The expression "even beam" is quite as short as, and far more correct than, "even keel," the term generally used in this connexion.

Kilomètre (Gk. *χίλιοι*, "a thousand", *μέτρον*, "a measure", Fr. *mètre*).—A French measure of length, being 1000 mètres, and equal to about $\frac{5}{8}$ of an English mile. It is sometimes called *The Metrical Mile.*—See **Mètre, Mile.**

Knot.—A division of the log-line; so called from the line being divided into equal parts by pieces of string rove through the strands and knotted in order. When the 28^s log-glass is used, the length of the knot is 47·29 feet.—See **Log.**

Knot.—The common term for the nautical mile used at sea, the rate at which the ship is sailing being measured by the "knots" run out on the log-line. The actual nautical miles vary in length in different latitudes, but seamen require a definite constant measure. This should strictly be the average length of the nautical mile or mean value of a minute of latitude, which is 6072·86 feet, but the approximate figure 6080 feet is generally taken as more convenient. There is no Admiralty authority defining the value of the knot or seaman's mile.—See **Mile.**

L.

l.—Of the letters used to register the state of the weather in the log-book, l indicates "*Lightning*".

L.—The initial of logarithm. It is used to indicate the *tabular logarithm* in contradistinction to the *actual logarithm*, which is referred to by the abbreviation *log.*—See **Log.**

Lagging.—See **Tide-day, Priming and Lagging.**

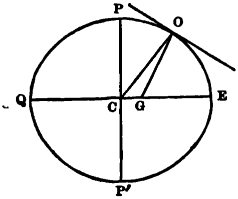
Land.—On *leaving the land* a departure should be secured at the latest period. To insure this, it should be set at the close and dawn of day, and at the coming on of a fog. On *making the land* it is prudent to charge the ship's place with some inaccuracy and keep a most vigilant look-out; when any uncertainty rests on the longitude, it will be well to make the latitude of the port and then run along the parallel. As soon as the land is made the ship should at once be laid off by the reckoning. Caution is required on special points, such as currents, coral reefs, etc., according to the nature of the region. Among the indications of the neighbourhood of land which may at times prove valuable, may be mentioned the presence of birds, and a lowering in the temperature of the surface water.

Landfall.—The land first sighted at the termination of a voyage. To make a good landfall is to make the land as expected.

Landmark.—A conspicuous object on shore, the bearings of which give the position of the ship and serve to guide her course.

Latitude (L. *latitudo*, "breadth").—See **Longitude and Latitude.**

Latitude of an Observer.—When the earth is regarded as a *sphere* the latitude of the place of an observer is its angular distance from the equator and it is measured by the arc of the terrestrial meridian of the observer intercepted between the equator and the place, or by the corresponding angle at the centre of the sphere. The earth, however, is in reality an *oblate spheroid*, and when its departure from the spherical form is taken into consideration, this arc and angle cease to measure each other. Hence the distinction between the *Latitude on the Spheroid* and the *Latitude on the Sphere*, or, in other terms also used, the *Geographical* or *Normal Latitude* and the *Geocentric* or *Central Latitude*, or the *True Latitude* and *Reduced Latitude*. The latitude on the spheroid, the geographical, normal, or true latitude, is the angle (EGO) which the normal, or perpendicular to the earth's surface at the place, makes with the plane of the equator. The latitude on the sphere, the geocentric, central, or reduced latitude, is the angle (ECO) which the line joining the place and the centre of the earth makes with the plane of the equator. The former of these is the latitude as determined by astronomical observations, the latter is deduced from it by the application of the correction tabulated under the heading "Reduction of the Latitude of Place for Figure of the Earth". Latitude is reckoned from the equator north and south to the poles from 0 to 90°. Longitude and latitude are the co-ordinates for defining position on the earth's surface.—See **Longitude and Latitude.**



Latitude on the Sphere, *Geocentric, Central,* or *Reduced,* as distinguished from *Latitude on the Spheroid, Geographical, Normal,* or *True.*—See **Latitude of an Observer.**

Latitude, Reduction of.—It is sometimes necessary to reduce the latitude as found by astronomical observation, which is affected by the spheroidal figure of the earth, to what it would be if the earth were a perfect sphere. This correction is given in Tables as "Reduction of the Latitude of Place for Figure of the Earth". Being the angle between the lines which would be vertical on the two suppositions, this quantity is also called the "*Angle of the Vertical*". It vanishes at the equator and at the poles, and attains its maximum when cot lat. $= \sqrt{1 - e^2}$, or at about 45° of latitude.

Latitude (Terrestrial), Parallels of.—Small circles of the terrestrial sphere parallel to the equator. They mark all the places on the earth which have the same latitude, and places of the same latitude are said to "be on the same parallel". Compare "Parallels of Declination", "Parallels of Latitude (Celestial)", "Parallels of Altitude".—See **Co-ordinates for the Surface of a Sphere.**

Latitude, Difference of.—The difference of latitude (abbreviated *Diff. lat.*) between two places is the arc of a meridian intercepted between their parallels of latitude.—See under **Difference.**

Latitude from.—The latitude of the place sailed from.

Latitude in, or **Latitude to.**—The latitude of the place sailed to.

Latitude in, and **Longitude in.**—Problem in geo-navigation. *To find the latitude in and the longitude in, having given the latitude from, the longitude from, and the course and distance between the two places.* Two general methods of solution—

(I.) By "MERIDIONAL PARTS"; from the formulæ—

$$\text{True diff. lat.} = \text{dist.} \times \cos \text{course}$$
$$\therefore \log \textit{true diff. lat.} = \log.\ \text{dist.} + \text{L} \cos \text{course} - 10.$$
$$\text{Diff. long.} = \text{mer. diff. lat.} \times \tan \text{course}$$
$$\therefore \log \textit{diff. long.} = \log.\ \text{mer. diff. lat.} + \text{L} \tan \text{course} - 10.$$

(II.) By "MIDDLE LATITUDE"; from the formulæ—

$$\text{True diff. lat.} = \text{dist.} \times \cos \text{course}$$
$$\therefore \log.\ \textit{true diff. lat.} = \log.\ \text{dist.} + \text{L} \cos \text{course} - 10.$$

$$\left.\begin{array}{l}\text{Dep.} = \text{true diff. lat.} \times \tan \text{course} \\ \text{Diff. long.} = \text{dep.} \times \sec \text{mid. lat.}\end{array}\right\}$$

$$\therefore \log. \textit{diff. long.} = \log. \text{tr. diff. lat.} + \text{L} \tan \text{course} + \text{L} \sec \text{mid. lat.} - 20.$$

In the special case of "PARALLEL SAILING"; the *lat. in* is the same as the lat. from; the *long. in* is found from the formula—

$$\text{Diff. long.} = \text{dist.} \times \sec \text{lat.}$$

$$\therefore \log. \textit{diff. long.} = \log. \text{dist.} + \text{L} \sec \text{lat.} - 10.$$

Latitude, how found.—

I.—IN GEO-NAVIGATION.

The latitude at the preceding noon being given, together with the distance run, and the course made good since, the latitude is found from the formula—

$$\text{True diff. lat.} = \text{dist.} \times \cos \text{course}$$

$$\therefore \log \textit{tr. diff. lat.} = \log \text{dist.} + \text{L} \cos \text{course} - 10.$$

II.—IN CELO-NAVIGATION.

In the figures of the following articles, the projection is uniformly made on the horizon NWSE; Z is the zenith; EQW the equator; P the north pole; P′ the south pole, and NZS the meridian. The letters X and Y are used to indicate the position of the body or bodies observed. The altitude is indicated by a, the zenith distance by z, the declination by δ, the polar distance by p, the co-latitude (or polar distance of the observer's zenith) by c, and the latitude by l. It must also be premised that the elevation of the pole is equal to the latitude of the place; for $NP = NZ - ZP = 90° - ZP = QP - ZP = QZ$.

The body observed may be the sun, the moon, a star, or a planet, the corrections for finding the true altitude from the observed, and for finding the declination at the moment of observation, varying in each case.

There are three classes of observations for determining the latitude. (I.) MERIDIAN ALTITUDES; (II.) CIRCUM-MERIDIAN ALTITUDES, or altitudes when the body is near the meridian, and which can be "reduced" to corresponding meridian altitudes; and (III.) Ex-meridian Altitudes, or altitudes when the body is away from the meridian: pairs of such altitudes are "combined" for the resolution of the problem.

(I.) Meridian Altitudes.

(i.) By an observation of One Meridian Altitude of a body.

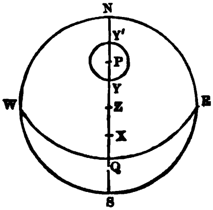
1. *Above the elevated pole.*

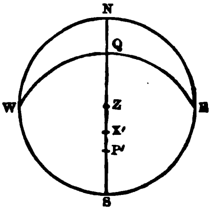
If δ is considered $\pm$ according as it and the elevated pole are of the $\genfrac{}{}{0pt}{}{\text{same}}{\text{different}}$ name; and z (measuring always *from* Z) be considered $\pm$ according as it is reckoned $\genfrac{}{}{0pt}{}{\text{from}}{\text{towards}}$ the elevated pole; then in every case,

$$l = z + \delta.$$

The different cases may, however, be considered separately.

(*a*) If the body (as X) is on the same side of the elevated pole and Z,





then according as l and δ are of the $\genfrac{}{}{0pt}{}{\text{same}}{\text{different}}$ name,

$$l = z \pm \delta.$$

(*b*) If the body (as X′) is between the elevated pole and Z, then

$$l = \delta - z \qquad\qquad \text{or } l = a - p.$$

2. *Below the elevated pole* (as Y′)

$$l = a + p \qquad\qquad \text{or } l = a + 90 - \delta.$$

(ii.) By combining observations of Two Meridian Altitudes of a body whose declination may be considered constant, viz., at the upper and lower culminations, $a = \mathrm{NY}$, $a_{,} = \mathrm{NY}'$

$$\text{then } l = \tfrac{1}{2}(a + a_{,}).$$

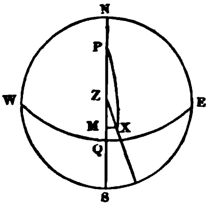
(II.) CIRCUM-MERIDIAN ALTITUDES.

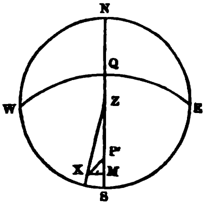
Method i.—Using Estimated Latitude.

Observe a number of altitudes when the body is near the meridian, noting the time, and, when practicable, an equal number should be taken on each side of the meridian. By this means a much more accurate result may be obtained than by taking a single altitude.

1. *Above the elevated pole.*

Let z' be the mean true zenith distance deduced from the mean of the observed altitudes, and z the unknown meridian zenith distance; h the mean hour-angle found from the times; let l' be the approximate and l the true latitude. Then from the triangle PZX (the upper or lower sign being used according as l' and δ have the same or different names),





$$\operatorname{Cos} h = \frac{\cos z' \mp \sin l' \sin \delta}{\cos l' \cos \delta}$$

Whence is deduced

$$\operatorname{Vers}(l' \mp \delta) = \operatorname{vers} z' - \cos l' \cos \delta \operatorname{vers} h$$

$$\therefore \operatorname{Vers} z = \operatorname{vers} z' - \cos l' \cos \delta \operatorname{vers} h.$$

[Assume vers $\rho = \cos l' \cos \delta$ vers h

$= 2 \cos l' \cos \delta$ hav h

$\therefore$ Log. vers $\rho = 6{\cdot}301030 + \text{L} \cos l' + \text{L} \cos \delta + \text{L}$ hav $h - 30$ from which vers ρ is found. Or, hav $\rho = \cos l' \cos \delta$ vers h.

$\therefore$ L hav $\rho = \text{L} \cos l' + \text{L} \cos \delta + \text{L}$ vers $h - 20$.]

$$\text{Vers } z = \text{vers } z' - \text{vers } \rho$$

Then as in (I.) 1, $l = z + \delta$.

If the latitude thus found differs much from the assumed latitude, the calculation must be repeated with the new value l instead of l', and thus a nearer approximation to the true latitude be found.

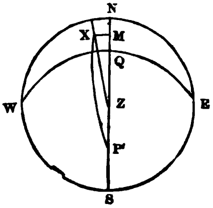
2. *Below the elevated pole.*

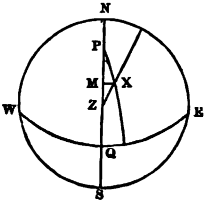
If $a_{,}'$ be the mean true altitude, and $a_{,}$ the meridian altitude below the pole, it may be similarly proved,

$$\text{Vers } (90^\circ + a_{,}) = \text{vers } (90^\circ + a_{,}') - \cos l' \cos \delta \text{ vers } (12^{\text{h}} \sim h)$$
$$= \text{vers } (90^\circ + a_{,}') - \text{vers } \rho.$$

Then as in (I.) 2, $l = 90^\circ + a_{,} - \delta$.

Method ii.—Independently of Approximate Latitude.





From X drop a perpendicular XM ($= \phi$) upon the meridian, and let MP = M, MZ = N; then from the right-angled triangles XMP, XMZ,

$$\text{Cos } h = \tan M \cot p \qquad \left.\begin{array}{l}\cos p = \cos M \cos \phi \\ \cos z = \cos N \cos \phi\end{array}\right\}$$

$$\therefore \text{ Tan } M = \cos h \cot \delta \qquad \therefore \cos N = \sin a \operatorname{cosec} \delta \cos M$$

$$\text{L} \tan M = \text{L} \cos h + \text{L} \cot \delta - 10;$$

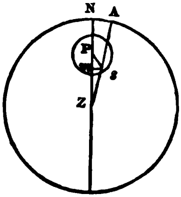
$$\text{L} \cos N = \text{L} \sin a + \text{L} \operatorname{cosec} \delta + \text{L} \cos M - 20.$$

$$\text{Co-latitude} = M \mp N,$$

the upper sign being taken if the sun (the body observed) passes the meridian outside the pole and zenith, and the lower if it passes between them. If the latitude and declination are of different names, tan M is negative, and the arc taken from the tables must be subtracted from 180°. In finding tan M, unless a proportion is found for odd seconds, the result may be several minutes in error.

The "estimated latitude" method is the better of the two described.

The "Reduction to the Meridian", or the reducing an altitude observed near the meridian to the meridian altitude, may be effected by the aid of Towson's Tables [published by J. D. Potter, Poultry, London].



Method iii.—Case of the Pole Star.

Draw the perpendicular to the meridian sm, let $Pm = m$, and p be the polar distance expressed in minutes of arc.

By modifying the preceding general formulæ, and introducing a instead of z, they become specially applicable to the observation of the pole star.

$$\text{Tan } m = \cos h \,.\, \cot \delta \qquad \sin (l + m) = \sin a \,.\, \cos m \,.\, \operatorname{cosec} \delta$$

$$\text{L.} \tan m = \text{L} \cos h + \text{L} \cot \delta - 10;$$

$$\text{L} \sin (l + m) = \text{L} \sin a + \text{L} \cos m + \text{L} \operatorname{cosec} \delta - 20.$$

$$\text{And} \qquad l = (l + m) - m.$$

But the case admits of a simpler solution. As, the star's true altitude, is nearly equal to Nm, and hence, approximately,

$$l = a - p \cos h,$$

$p \cos h$ being positive when h lies between 0^h and 6^h, or between 18^h and 24^h; negative when it lies between 6^h and 18^h. The reduction of $p \cos h$ may be facilitated by the use of the Traverse Table, entering with h as a course and p as a distance.

Except in high latitudes, this approximation to the latitude will rarely be in error above 2′; but where the reduction is required accurately, it may be computed from the nearer approximation

$$l = a - p \cos h + \tfrac{1}{2} \sin 1'' (p \sin h)^2 \tan a.$$

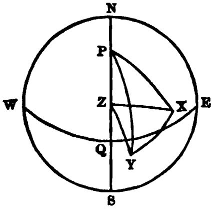
The labour is very much diminished by the use of tables derived from this expresssion and given in the "Nautical Almanac".

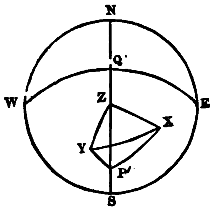
(III.) Ex-meridian Altitudes.

The latitude is found by the *combination* of two such altitudes ("Double Altitudes"), either of the same body at different times, or of different bodies at the same time ("Simultaneous Altitudes"), or of different bodies at different times.

Method i.—Direct. *General.*

Let p and p' be the polar distances of the body or bodies in the posi-





tions X and Y (X having the greater azimuth); z and z' the zenith distances; P the polar angle, which, in the case of the same body a different times, is the "elapsed time"; in the case of different bodies at the same time, is the difference of the right ascensions; and in the case of two bodies observed at different times, is a combination of the elapsed time and the difference of right ascensions. Then we successively determine the following arcs, thus finally getting the co-latitude, and hence the latitude:—

Arc i.—XY. In the triangle XPY,

$$\text{Vers XY} = \text{vers}\,(p - p') + \text{vers S}$$

$$\text{Havers S} = \sin p \sin p' \sin^2 \frac{\text{P}}{2}$$

or in the logarithmic form,

$$\text{L hav S} = \text{L} \sin p + \text{L} \sin p' + \text{L hav P} - 20$$

$$\text{tab vers i.} = \text{tab vers}\,(p - p') + \text{tab vers S.}$$

[For cases where the declination is considered the same for the two positions, $\text{S} = \text{i}$, and

$$\text{L hav i} = \text{L} \sin p + \text{L} \sin p' + \text{L hav P} - 20.]$$

Arc ii.—PXY. In the triangle XPY,

$$\text{Sin}^2 \frac{\text{PXY}}{2} = \frac{\sin \frac{1}{2}\,(p' + \overline{\text{XY} \sim p}) \sin \frac{1}{2}\,(p' - \overline{\text{XY} \sim p})}{\sin \text{XY} \sin p}$$

$$\text{L hav ii.} = \text{L cosec i.} - 10 + \text{L cosec}\, p - 10 + \tfrac{1}{2}\,\text{L hav}\,(p' + \overline{\text{i.} \sim p})$$
$$+ \tfrac{1}{2}\,\text{L hav}\,(p' - \overline{\text{i.} \sim p}).$$

Arc iii.—ZXY. In the triangle XZY,

$$\text{Sin}^2 \frac{\text{ZXY}}{2} = \frac{\sin \frac{1}{2}\,(z' + \overline{\text{XY} \sim z}) \sin \frac{1}{2}\,(z' - \overline{\text{XY} \sim z})}{\sin \text{XY} \sin z}$$

$$\therefore \text{L hav iii.} = \text{L cosec i.} - 10 + \text{L cosec}\, z - 10 + \tfrac{1}{2}\,\text{L hav}\,(z' + \overline{\text{i.} \sim z})$$
$$+ \tfrac{1}{2}\,\text{L hav}\,(z' - \overline{\text{i.} \sim z}).$$

Arc iv.—PXZ.

$$\text{PXZ} = \text{PXY} \mp \text{ZXY}$$

$$\text{iv.} = \text{ii.} \mp \text{iii.}$$

Arc v.—PZ (Co-latitude). In the triangle PXZ,

$$\text{Vers PZ} = \text{vers}\,(p - z) + \text{vers S}$$

$$\text{Havers S} = \sin p \sin z \sin^2 \frac{\text{PXZ}}{2}$$

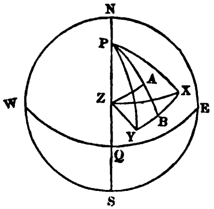
$$\text{or L hav S} = \text{L} \sin p + \text{L} \sin z + \text{L hav iv.} - 20$$

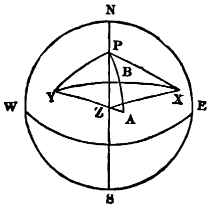
$$\text{tab vers v.} = \text{tab vers}\,(p - z) + \text{tab vers S.}$$

In taking the observations, the nearer the difference of azimuth of the two bodies or positions approaches 90° the better, and the less will be the effects on the resulting latitude of any errors in the observed altitudes. When the ship has moved between the two observations, the first altitude must be corrected for the "run" of the ship in the interval. This may be done with the aid of the Traverse Table, entering with the angle between the bearing of the body at the first observation and the ship's course made good in the interval as a course, and the distance run as a distance; the corresponding diff. lat. will be the correction to be *added* when the course is less than eight points, to be *subtracted* when greater. The resulting latitude will be that of the second place of observation. [**Run.**]

Method ii.—Ivory's. *For cases where the declination is considered the same for the two positions.*

Draw PB the perpendicular bisecting XY in B; and ZA the perpendicular from the zenith upon PB (or PB produced) meeting it in A. Then we successively determine the following arcs:—





Arc i.—BX.

$$\text{Sin BX} = \sin\frac{P}{2}\sin p$$

$$\therefore \text{ L sin i.} = \tfrac{1}{2}\text{ L hav P} + \text{L cos }\delta - 5.$$

Arc ii.—PB.

$$\text{Cos PB} = \frac{\cos p}{\cos \text{BX}}$$

$$\therefore \text{ L cos ii.} = \text{L sin }\delta + \text{L sec i.} - 10.$$

(When the polar distance exceeds 90° the supplement of the arc found in the tables must be taken.)

Arc iii.—ZA.

$$\text{Sin ZA} = \frac{\cos\frac{1}{2}(a + a')\sin\frac{1}{2}(a - a')}{\sin \text{BX}}$$

$$\therefore \text{ L sin iii.} = \text{L cosec i.} + \text{L cos }\tfrac{1}{2}(a + a') + \text{L sin }\tfrac{1}{2}(a - a') - 20.$$

Arc iv.—BA.

$$\text{Cos BA} = \frac{\sin\frac{1}{2}(a + a')\cos\frac{1}{2}(a - a')}{\cos \text{BX}\cos \text{ZA}}$$

$$\therefore \text{ L cos iv.} = \text{L sec i.} + \text{L sec iii.} + \text{L sin }\tfrac{1}{2}(a + a') + \text{L cos }\tfrac{1}{2}(a - a') - 30.$$

Arc v.—PA.

$$\text{PA} = \text{PB} \mp \text{BA}$$
$$\text{v.} = \text{ii.} \mp \text{iv.}$$

Arc vi.—PZ (co-latitude).

$$\left.\begin{array}{c}\text{Cos PZ}\\ \text{or}\\ \text{sin lat}\end{array}\right\} = \cos \text{PA}\cos \text{ZA}$$

$$\therefore \text{ L sin lat} = \text{L cos v.} + \text{L cos iii.} - 10.$$

This method may be rendered general by applying a correction (1′) to the computed latitude for any change of declination in the interval between the two observations. By this means it may be used for double altitudes of the sun. Let c be the change of declination in half the elapsed time, then—

$$l' = c \frac{\sin \text{iii.}}{\cos l \sin \frac{P}{2}}$$

This correction is additive when the second altitude is the greater and the polar distance decreasing, or when the second altitude is the less and the polar distance increasing; otherwise it is subtractive.

Another way of obtaining accuracy is to use the mean of the polar distances.

Riddle's Extension of Ivory's Method.

Determining the position in full.

Let H = Hour angle ZPA;
Then $\sin H = \sin \text{iii.} \sec l$

(H ± P) ± equation of time = mean time at place where the two observations were taken.

When the declination changes between the two observations, as in the case of the sun, a correction (h′) must be applied to the computed middle time for the change of declination during the half-elapsed time;

$$h' = c \tan l \cos H \operatorname{cosec} \frac{P}{2} - c \cot p \cot \frac{P}{2} = m \mp n$$

(m — n) or (m + n) being taken according as the latitude and declination have like or unlike names, and the result is to be added or subtracted from H the middle time according as the polar distance (from the elevated pole) is decreasing or increasing.

The G.M.T. at the mean between the two observations being obtained from the chronometer, the longitude is known.

The case of *Simultaneous Altitudes of Two Stars* is one of great practical use; the best time for observing them being the morning and evening twilight, when stars and horizon both are clearly and distinctly visible

The work of reduction for certain pairs of stars is very much facilitated by the use of Shadwell's Star Tables.

Method iii.—Sumner's.

Determining the Position in Full.

Corresponding to the two altitudes, two "lines of equal altitude" are projected on a Mercator's chart, and these give, by their intersection, the *position* (in full) of the ship. The explanation of this method, therefore, belongs to a more general head; but it is noticed here because, when the latitude only is required, the watch used to note the elapsed time may be considered to show time at any meridian we may please to assume, and the latitude is therefore determined without reference to the error of chronometer.

Latitude of a Heavenly Body.—The angular distance of the body from the ecliptic. It is measured by the arc of the circle of latitude passing through the place of the body, intercepted between the ecliptic and that place, or by the corresponding angle at the centre of the sphere. Latitudes are reckoned from the ecliptic to its poles, north and south from 0 to 90°. Longitude and latitude are the ecliptic co-ordinates for defining the positions of points on the celestial concave, and indicating their positions relatively to each other.—See **Longitude and Latitude.**

Latitude (Celestial), Circles of.—Great circles of the celestial concave passing through the poles of the ecliptic, and so called because "latitude" is measured on them. They are also called "*Circles of Longitude*", as marking out all points that have the same longitude.—See **Co-ordinates for the Celestial Sphere.**

Latitude (Celestial), Parallels of.—Lesser circles of the celestial concave parallel to the ecliptic. They mark all the points of the heavens which have the same latitude. Compare "Parallels of Declination", "Parallels of Altitude".—See **Co-ordinates for the Celestial Sphere.**

Latitude, Heliocentric and Geocentric (Gk. ἥλιος, "the sun"; γῆ, "the earth"; and κέντρον, "the centre").—Terms applied especially to the planets. The distance of the planets from the earth is small compared with that of the fixed stars, and hence the place of any one of them in the celestial concave varies with the position of the spectator in different parts of the earth's orbit. Thus, viewed from the earth as centre, we have the geocentric place of a planet and the corresponding geocentric latitude and longitude. On the contrary, if viewed from the sun as centre we have the heliocentric place of the planet, and the corresponding heliocentric latitude and longitude. The geocentric differs from the heliocentric place of a planet by reason of that parallactic change of apparent situation which arises from the earth's motion in her orbit.

Lead.—A piece of lead attached to a string used for taking soundings, or for certifying that the water is above a certain depth.

Lead-arming.—A lump of tallow pressed into the lower end of the sounding-lead, for the purpose of ascertaining the nature of the sea bottom.

Lead-line.—The line attached to the lead used for taking soundings. This line is marked at the 10 fathoms (leather with a round hole) and the 20 fathoms (piece of cord with two knots); intermediate fathoms between these, at 3 (leather), 5 (white rag), 7 (red rag); also at 13 (blue rag), 15 (white rag), 17 (red rag). These depths are called *Marks*, and those which are not thus indicated *Deeps;* and the leadsman, in singing out the soundings, cries either, "By the Mark", or "By the Deep". The word "deep" is a corruption of *dip*, for in estimating the depth with the hand-lead, when it lies between the fathoms marked the line has to be lifted out of the water and "dipped" down again. The only fractions of a fathom used are a half and a quarter—*e.g.* 7½ fathoms is "and a half seven"; 7¾ is "a quarter less eight". The hand lead-line is limited to 20 fathoms. The deep-sea lead-line is marked in a similar manner up to 20 fathoms, after which every subsequent 1 fathoms is indicated by a piece of cord with an additional knot, and between these a piece of leather marks the 5 fathoms.

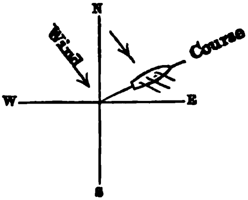
Lead, Hand.—The sounding-lead for shallow water, so called from it being thrown by the "hand". The use of it is not only to obtain soundings, but to satisfy the pilot that the water is above a certain depth. The "leadsman", standing in the chains, swings the lead once or twice round, and then "casts" it forward as far as he can. He draws the line tight from the lead at the instant the ship in her progress places him perpendicularly over it. It descends about 10 fathoms in the first six seconds. The hand-lead weighs 14 lbs., and is attached to about 25 fathoms of line. A small lead of about 5 lbs. or 6 lbs. is sometimes used.

Lead, Deep-Sea.—The sounding-lead for deep water. Its weight is 28 lbs., and it is attached to a line of 100 fathoms or more wound on a reel. In heaving it, the ship's way is reduced if necessary, and the line having been passed aft outside of all, the lead is carried forward and dropped from the lee cathead, or fore-chains. The error of the soundings is generally in excess, as the line can seldom be stretched straight from the lead.

Sir William Thomson has invented a "Navigational Sounding Machine" for the purpose of obtaining soundings from a ship running at full speed in water of any depth not exceeding 100 or 150 fathoms. See "Journal of the Royal United Service Institution", vol. xxii. No. xciv.

League (Sp. *legua*).—Three nautical miles.

Leap Year or **Bissextile.**—The year which the calendar regulates to consist of 366 instead of 365 days. It derives its name from leaping over a day more than the ordinary year, which day was not legally recognized. The 24th of February and the following day in the bissextile year were considered in the Roman law as one day; and so in the English calendar, by statute 21 Henry III., the intercalated day and that preceding it were considered legally as one (" Computetur dies ille et dies proxime precedens pro uno die ").—See **Bissextile** and **Calendar.**



Leeway.—The angle which the ship's track indicated by her wake makes with her fore-and-aft line or keel. When the ship is not going before the wind she will not only be forced forward in the direction of her head, but, in consequence of the wind pressing against her sideways, her actual course will be to " leeward " of the apparent course she is lying. Experience and observation are required to judge what amount of leeway to allow in each case. It is one of the corrections to be applied in reducing the compass course to the true course in the day's work; the correction being allowed to the *right* when the ship is on the *port tack*, *i.e.* port side to windward, and to the *left* when on the *starboard* tack. A simple figure will always remove any doubt in making such corrections.

Length of a Wave.—The horizontal distance between two adjacent crests, or two adjacent hollows.

Leo, Constellation of (L. " The Lion ").—The fifth constellation of the zodiac, coming between Cancer and Virgo, and situated near the Great Bear on the opposite side of it to the pole star. Its four principal stars form a trapezium. α *Leonis*, called also *Cor Leonis* (" The Lion's Heart ") and *Regulus*, may be found by joining α and β Ursæ Majoris (" The Pointers ") and continuing the line about twice the length of that constellation; this line also passes γ *Leonis*. β *Leonis*, called also *Denebola* (" The Lion's Tail "), is found by joining η Ursæ Majoris (the last star in the tail of the Great Bear) with Cor Caroli, and continuing it by about twice its length. α *Leonis*, mag. 1.2; 1882, R.A. $10^{h}\ 2^{m}$, Dec. + 12° 32′.

β *Leonis*, mag. 2; 1882, R.A. $11^h\ 43^m$, Dec. + 15° 14′. γ^1 *Leonis*, mag. 2; 1882, R.A. $10^h\ 13^m$, Dec. + 20° 26′. δ *Leonis*, mag. 2.3; 1882, R.A. $11^h\ 8^m$, Dec. + 21° 10′.

Leo, Sign of.—The fifth sign of the ecliptic, including from 120° to 150° of longitude. Owing to the precession of the equinoxes, the constellation Cancer, and not Leo, is at present in this sign. The sun is in Leo from 22nd July to 23rd August. Symbol ♌.

Lesser or Small Circles.—Lesser or Small Circles of the Sphere are sections by planes which do not pass through the centre. Thus parallels of latitude are lesser circles of the terrestrial sphere; parallels of declination, parallels of latitude, and parallels of altitude are lesser circles of the celestial sphere.—See **Circles of the Sphere.**

Level of the Sea.—The zero plane from which heights and depths are reckoned. As the actual sea-level is constantly varying with the tides, it is necessary to define more particularly the standard for comparison. The *Mean Level of the Sea* is the middle plane between the levels of high and low water. Though the range of the tide may vary considerably, this mean level fluctuates within very narrow limits.

Level, Spirit.—An instrument for ascertaining the horizontality of a line or plane. It consists of a hollow glass tube of uniform bore closed at both ends, and nearly filled with a fluid of great mobility, such as spirit of wine or sulphuric ether, an air-bubble remaining enclosed. The tube is not quite straight, but has a slight uniform curvature, the convex side being placed upwards. The air-bubble will always occupy the highest position, and this will be the middle point of the tube when the instrument stands in a perfectly horizontal position as regards its length. To ascertain the horizontality of a given line, the level is first placed upon it, and the position of the bubble noted; it is then reversed end for end, and the bubble must remain in the same position as before.

For a plane the test must be repeated in a direction perpendicular to the first pair of observations. Astronomical levels are furnished with a divided scale by which the position of the ends of the bubble can be accurately noted.

Libra, Constellation of (L. "The Balance").—The seventh constellation of the zodiac, coming between Virgo and Scorpio. It contains two principal stars, α *Libræ*, the *North Balance*, and β *Libræ*, the *South Balance*, the former bisecting the line joining Spica and Antares, the latter with Spica and Arcturus forming a triangle. α *Libræ*, mag. 2.3; 1882, R.A. $14^{h}\ 44^{m}$, Dec. − 15° 33′. β *Libræ*, mag. 2; R.A. $15^{h}\ 11^{m}$, Dec. − 8° 57′.

Libra, Sign of.—The seventh sign of the ecliptic, including from 180° to 210° of longitude. Owing to the precession of the equinoxes, the constellation Virgo, and not Libra, is at present in the sign. The sun is in Libra from 22nd September to 23rd October. Symbol ♎.

Libra, First Point of.—The "*Autumnal Equinoctial Point*", one of the points where the ecliptic crosses the equinoctial, is so-called as being the commencement of the sign Libra.—See **Equinoctial Points.**

Limb (L. *limbus*, "a border").—1. The outer edge of the disc of a heavenly body. The initials U. L., L. L., F. L., N. L., stand respectively for "upper limb", "lower limb", "further limb", "nearer limb". In the case of the moon the terminator must not be used as a limb.

2. In astronomical instruments, such as the sextant, the limb is the graduated arc.

Line.—"The Line" is the colloquial abbreviation for "*The Equinoctial Line*". It is where the plane of the equinoctial cuts the surface of the earth, and is therefore coincident with the equator; all places situated upon it have the day of equal length with the night throughout the year, the lengthening of the day owing to refraction and dip being neglected. Passing from one hemisphere to the other is commonly described as "Crossing the Line".

Local Attraction.—The term indicating the magnetic influence on the compass needle of volcanic and other natural magnetic bodies, or of artificial iron accidentally in the locality of the ship, but extraneous to it. The islands of St. Helena and Ascension are instances of the former, while in the latter are included the iron cranes, water-pipes, and pillars which generally surround our docks, and adjacent iron ships. The term is sometimes applied to the attraction arising from the ship itself, which is the habitat of the compass, but it would be desirable to discontinue this use of the word.

Local Deviation.—The angle through which the compass needle is deflected in consequence of the disturbing influence of "*local attraction*". We suggest the application of the unappropriated simple term "*Deflection*" for this correction. The simple term "*Deviation*" is sufficient, without any qualifying word, to indicate the correction rendered necessary from the effects of the iron of the ship which carries the compass.—See **Compass Corrections.**

Local Time.—Local time is that which is reckoned at each particular place from an epoch or initial instant determined by local convenience; and is thus distinguished from time in the abstract, which is common to the whole universe, and therefore reckoned from an epoch independent of local situation.—See under **Time.**

L. M. T.—The initials for "*Local Mean Time*", sometimes used in contradistinction to *G. M. T.*, "*Greenwich Mean Time*". We, however, recommend adherence to the more common S. M. T., as the correlative of G. M. T. To the navigator S. M. T., "Ship's Mean Time", sounds more practical than Local Mean Time; and if we want it to be received in a more general sense, it may stand for "Mean Time at the Station of Spectator". The objection to the term "Local Mean Time" here is, that *local time* properly includes Greenwich time, for it is opposed to *time in the abstract*, which is common to the whole universe, and therefore reckoned from an epoch independent of local situation.—See **Time**.

Log (Sax. *log*, "a hewn-up trunk of a tree", so called from the word *ligen*, because it "lies", as it were, immovable. Hence the appropriateness of the name *log* as applied to the piece of wood which lies dead upon the water and does not participate in the motion of the ship).—An instrument consisting of the three parts, the *log-ship*, *log-line*, and *log-glass*, by which the rate of sailing, and consequently the distance sailed over in any given time, is found in geo-navigation. It is the characteristic instrument of that method of navigation when the navigator leaves the vicinity of land and resorts to "dead reckoning". The general principle of it is simply this. A light substance thrown from the stern of a ship in motion, as soon as it touches the water ceases to participate in the motion of the vessel, and will be left behind on the surface of the sea. After a certain short interval, if the distance of the ship from the stationary float be measured, this will give the rate of sailing with more or less accuracy. The log-ship is this float, the log-line measures this distance, and the log-glass defines the interval.

The Log-ship ("log-chip"), is a thin wooden quadrant of about five inches radius, loaded on the circular edge with lead sufficient to make it swim upright in the water. The object of this is to impede its being dragged through the water by the log-line (which is fastened to it) while running out. The manner in which the log-line is attached is such that this purpose is served only while a measurement is being made. At each end of the arc of the log-ship is a hole, through one of which holes the log-line is rove and knotted; a piece of line about eight inches in length is spliced into it at that distance from the log-ship, having at the other end a peg of wood or bone, which, when the log is hove, is firmly pressed into the unoccupied hole. It remains thus while the line is running out, but comes away when the line is being hauled in. The log-ship is sometimes bored with a hole at each of its three corners. Instead of this piece of wood, a canvas bag with a small hoop at its mouth like a funnel is sometimes used.

The Log-line is a line of about 150 fathoms, one end being attached as above described to the log-ship, and the other fastened to a reel on which the line itself is wound. At ten or twelve fathoms from the log-ship a conspicuous rag of bunting is placed, which marks off what is called the "stray-line", a quantity sufficient to let the log-ship go clear of the vessel before time is counted. The rest of the line, which constitutes the log-line proper, is divided into equal portions by bits of string fixed through the strands, and distinguished by the number of knots made in each; hence these divisions are called "knots". The length of a knot on the line depends upon the number of seconds which the log-glass used measures. The length of each knot must bear the same ratio to the nautical mile that the time of the glass does to an hour.

$$\frac{\text{Number of feet in 1 knot}}{\text{Number of feet in 1 mile}} = \frac{\text{Number of seconds of glass}}{\text{Number of seconds in 1 hour}}$$

If we use a half-minute glass:—

$$\text{Feet in a knot} = \frac{30}{3600} \times (\text{feet in a mile}).$$

Formerly it was considered that a degree of a terrestrial great circle was 60 miles each of 5000 English feet, and the length of a knot was calculated as $\frac{5000}{120} = 41\frac{2}{3}$, or, in round numbers, 42 feet. This was the old length of the knot; and even after it was found by experience to be too short, rather than alter it mariners often preferred reducing their glasses to 25 or 24 seconds. In 1635, Norwood estimated a degree to measure 367,200 feet (about 69½ English miles), and hence, according to him, the nautical mile was $\frac{367,200}{60}$ or 6120 feet. This gives the length of a knot $\frac{6120}{120} = 51$ feet. It is usual now to regard the nautical mile as being 6080 feet. [See **Mile.**] In this case, with a 30^s

glass, the length of the knot on log-line will be 50⅔ feet; with a 28^s glass its length will be 47·3 feet. The knot is supposed to be divided into eight equal parts or "fathoms," that being nearly their actual measurement. It is now customary, however, to use the more convenient decimal subdivision.

The Log-glass is a sand-glass of the same shape and construction as the old "hour-glass". There are two log-glasses used; the *Long-glass*, which runs out in 30^s or 28^s, and the *Short-glass*, which runs out in half the time of the long one. If the ship is going less than five miles an hour the long-glass is used; when she is going at a greater rate the short-glass is used, and the number of knots indicated doubled, the log-line being constructed for the long-glass. The glasses supplied to the Royal Navy run 28^s and 14^s.

Heaving the Log.—Using the compound instrument above described is called "Heaving the Log". It is thrown from the stern. One man holds the reel on which the log-line is wound, and another the log-glass in an almost horizontal position. An officer of the watch, having cautioned the helmsman to keep the ship steady on her course, takes the log-ship and presses the peg into its place (except the vessel is going very fast, when the arrangement is superfluous); he then unwinds a sufficient quantity of line and holds it "faked" (not "coiled") in his hand, and having ascertained that there is a "clear glass," throws the log-ship well out to leeward, so as to clear the eddies of the wake, and in such a manner that it may enter the water perpendicularly, and not fall flat upon it. The line runs through his hand, and when he feels the bunting rag which marks off the stray line, he cries out "turn!" The glass-holder answers "done!" When the vessel is before a heavy sea, the line should be paid out rapidly when the stern is rising, and the reel retarded when the line slackens in consequence of the stern falling. The moment the glass is run out the glass-holder cries "stop!" when the reel is immediately stopped, and the length of the line run out read off, any portion above a definite knot being estimated. This gives the rate of sailing, subject, however, to the effects which may be produced by currents. The log is hove every hour, and ought to be also whenever the course is changed.

Log Adjustments.—The log in all its parts requires to be periodically adjusted. (1) The log-ship must be examined and the peg found to fit sufficiently tight. (2) The log-line shrinks unequally, and repeatedly requires to be verified. In every ship there should be nails placed in the deck at the proper distance to measure the distance of the knots. When the log-line is thus examined it should be wetted. (3) The log-glass should often be compared with a watch which has a seconds' hand or with a seconds' pendulum. Such a pendulum may easily be constructed by hanging from a peg a musket-ball by a small thread 38⅛ inches long from the centre of the ball to the peg. In damp weather the sand is retarded and sometimes hangs together. One end of the glass is stopped with a cork, which can be taken out whenever the sand wants drying, or its quantity correcting. It is a very useful accomplishment for an observer on board ship to be able to count seconds correctly for a short period.

Log Errors.—The log may be found to be out of adjustment after observations have been made, and then it is necessary to acknowledge the errors and make allowances for them.

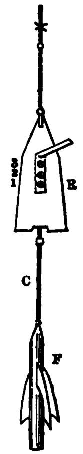
Let L be the true length the knot on the line should be, and N the number of such length run out; l the actual false length of the knot on the line, and n the number of these run out. Then, since the same length of line has run out, however it is divided,

$$L \times N = \text{length run out} = l \times n$$

$$\therefore \frac{L}{l} = \frac{n}{N}$$

Log, Ground.—A log adapted for use in shoal water where the set of the tides or current is much affected by the irregularity of the channel or other causes, and when at the same time the shore, if visible, presents no distinct objects by which to fix the ship's position. It consists of a small lead and a line divided as the common log-line. When hove, the lead remains fixed at the bottom, and the line thus exhibits the effect of the combined motion of the ship through the water, and that of the water itself,—the current. The ground log therefore gives at once compass course and distance made good.

Log, Massey's Patent.—Called after the patentee, Edward Massey. An instrument for showing the distance a ship actually goes through the water. It consists of a rotator or fly F, and a register R, the whole being towed astern by a line varying from 20 to 50 fathoms according to the size of the vessel, an essential point being to keep the machine out of the eddy of the ship's wake. As it is thus drawn along through the water in a horizontal position, the oblique direction of the vanes causes the fly to rotate, and this motion is communicated by means of the connecting cord C to the wheel-work within the register, and sets in motion the indices of the dials 1, 2, 3. The vanes of the rotator are so adjusted by very accurate experimental trials to the internal machinery of the register, that when the ship has towed the instrument through one mile (whether quickly or with mere steerage-way), the index of the first dial will have made one complete revolution, the index of the second will have moved through one tenth, and the index of the third through one hundredth of a revolution, and this is repeated for every subsequent mile. By this means 100 miles can be registered without taking in the log. Every time, however, the course is changed the log must be taken in, and a fresh commencement of the register made.



Log-book.—The official record of proceedings on board ship, deriving its name from its containing the important register of the log indication. It is strictly a journal, each page being ruled for one day. In the merchant service it is still the custom to begin the day at noon. In the Royal Navy the time is reckoned as on shore, from midnight, and the hours carried on to 12 or noon, and then to 12 or midnight again. A form is authorized for use in Her Majesty's Navy.

log.—The abbreviation of *logarithm*, as log. N, log. sin. a. Tables of the logarithms of the trigonometrical ratios give the actual logarithms increased by 10 in order that the inconvenience of negative characteristics may be avoided in the work of computation. Thus, tab. log. sin $a =$ log. sin $a + 10$, tab. log. hav $a =$ log. hav $a + 10$. To avoid all confusion the large initial letter L may with advantage be used for tab. log., the abbreviation *log.* being restricted to signify the actual logarithm. Thus, log. sin a $=$ L sin $a - 10$, log. hav $a =$ L hav $a - 10$.

Logarithms. (Gk. λογῶν ἀριθμὸς, "the number of ratios", *i.e.* the number of times an increase is made in a certain ratio when approximating to a given quantity).—*Definition.*—The logarithm of a number N is the value of x, which satisfies the equation $a^x = N$, where a is some given number, and is called the *Base*. The logarithm of N to base a is written $\log._a N$. Example.—If a be 10, the logarithm of 100 is 2, that of 1000 is 3, and that of any number between 100 and 1000 will be greater than 2 and less than 3, so that it may be represented by 2 and a fraction, the fraction being represented by a decimal. The integral part of a logarithm is called the *Characteristic* or *Index*, and the decimal part the *Mantissa* (L. overweight). Whatever positive value different from unity we give to a, it is possible to find the value of x, corresponding to all values of N, *i.e.* to find the logarithms of all numbers to the base a. These can then be registered in tables for use.

Logarithms, Computation by.—The use of logarithms greatly facilitates long calculations, for by the aid of a table of logarithms (1) *multiplication* may be performed by addition, (2) *division* by subtraction, (3) *involution* by multiplication, and (4) *evolution* by division. For let N and N′ be any two numbers, x and x' their logarithms to base a. Then $a^x = N$, $a^{x'} = N'$

$$\mathrm{N.N'} = a^x \times a^{x'} = a^{x+x'}$$

$$\text{by def. } x + x' = \log._a \mathrm{N.N'}$$

$$\therefore \log._a \mathrm{N.N'} = \log. \mathrm{N} + \log._a \mathrm{N'} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \tag{1}$$

$$\frac{\mathrm{N}}{\mathrm{N'}} = \frac{a^x}{a^{x'}} = a^{x-x'}$$

$$x - x = \log._a \frac{\mathrm{N}}{\mathrm{N'}}$$

$$\therefore \log._a \frac{\mathrm{N}}{\mathrm{N'}} = \log._a \mathrm{N} - \log._a \mathrm{N'} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \tag{2}$$

$$\mathrm{N}^p = (a^x)^p = a^{px}$$

$$px = \log._a \mathrm{N}^p$$

$$\therefore \log._a \mathrm{N}^p = p \log._a \mathrm{N} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \tag{3}$$

$$\sqrt[r]{\mathrm{N}} = (a^x)^{\frac{1}{r}} = a^{\frac{x}{r}}$$

$$\frac{x}{r} = \log._a \sqrt[r]{\mathrm{N}}$$

$$\log._a \sqrt[r]{\mathrm{N}} = \frac{1}{r} \log._a \mathrm{N} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \tag{4}$$

The logarithms of the numbers N and N′ are found in the tables, and the operation of addition, subtraction, multiplication, or division, as the case may be, performed on these; the result is regarded as a logarithm, and then the tables conversely used enable us to find the number corresponding to it. This quantity is the object of our investigation.

Logarithms, Systems of.—In the equation $a^x = \mathrm{N}$, a may be any positive quantity different from unity. There are, however, two systems of logarithms which possess peculiar advantages, called after their inventors, *Napierian logarithms* and *Briggs' logarithms.*

1. In the Napierian system the base is e, which represents the incommensurable quantity $1 + 1 + \frac{1}{1\,.\,2} + \frac{1}{1\,.\,2\,.\,3} + \frac{1}{1\,.\,2\,.\,3\,.\,4} + \,.\,.\,.\,.\,.$ or

2.7182818 . . . . This is a convenient base for analytical purposes, and is applied in the actual calculation of logarithms. Thus,

$$N = a^{x} = a^{\log ._{a} x}$$
$$\log ._{e} N = \log ._{a} N \log ._{e} a$$
$$\therefore \log ._{a} N = \frac{1}{\log ._{e} a} \log ._{e} N$$

Hence to find the logarithms to base a, the Napierian logarithms are multiplied by the quantity $\frac{1}{\log ._{e} a}$. This quantity, which is easily calculated, is called the *modulus* (L. "measure of proportion").

2. In Briggs' logarithms the base is 10, the same as the base of the common system of notation. The great advantage of this system is that the same decimal part serves for the logarithms of all numbers which differ from one another only in the position of the place of units relatively to the significant digits. Let $\text{Log}._{10} N = c + m$, where c is the characteristic or integral part, and m the mantissa or decimal part. Then $N \times 10^{p}$ will be a whole number, having the same significant digits as N, but with its units' place removed p places to the right. Then

$$\log ._{10} (N \times 10^{p}) = \log ._{10} N + \log ._{10} 10^{p} = (c + p) + m$$

which has $c + p$ for its characteristic, and the same mantissa m as $\log ._{10} N$. Again $\frac{N}{10^{p}}$ will be a decimal, having the same significant digits as N, but with its place of units removed p places to the left. Then

$$\log ._{10} \frac{N}{10^{p}} = \log ._{10} (N \times 10^{-p}) = \log ._{10} N + \log ._{10} 10^{-p} = \begin{cases} (c - p + m \text{ or} \\ -(p - c + m \end{cases}$$

according as $\frac{N}{10^{p}} >$ or $<$ than 1. In this case then, also, provided the logarithm be expressed so that the characteristic only is negative, the mantissa is the same as that of $\log ._{10} N$. Hence in tables of these logaarithms the mantissæ only are registered, and are always positive. The characteristic is assigned by the following rule:—The characteristic is equal to the number of places from the units' place, which is not included, to that of the most important digit, positive or negative according as the number itself is greater or less than unity. Where the two parts of the logarithm are of different signs, the negative sign is placed above the characteristic thus, $\bar{3}\cdot269746$. Good logarithmic tables are usually calculated for 4 or 5 digits; but the addition of auxiliary tables, called *tables of proportional parts*, furnishes an easy means of finding the logarithms of numbers consisting of more than this number of digits.

Logarithms of Trigonometrical Ratios.—Tables of these logarithms are used in nearly every problem of navigation.

1. *Table of the Logarithms of Sines, Cosines, Secants, Cosecants, Tangents, and Cotangents, and Table of Log-haversines.*—In order to avoid the inconvenience in calculations arising from the admixture of negative characteristics, in these tables 10 is added to every logarithm. Example—Sin 30° = $\frac{1}{2}$ = ·5 ∴ log. sin 30° = $\bar{1}\cdot698970$; the tabular logarithm is 9·698970. When, therefore, one of these tabular logarithms is used in any problem, the result must be corrected by the subtraction of 10. A convenient custom (which we hope to see more generally adopted) is to use the large letter L to indicate the tabular logarithm, while the abbreviation *log.* is restricted to signify the actual logarithm. Hence log. sin α = L sin $\alpha - 10$. The advantage of this rule in obviating all confusion will be apparent in reducing formulæ. Example—

$$x = \frac{a \sin \alpha \tan \phi}{b \cos \beta}$$

$$\begin{aligned} \therefore \log. x &= \log. a + (\mathrm{L} \sin \alpha - 10) + (\mathrm{L} \tan \phi - 10) - \log. b + (\mathrm{L} \sec \beta - 10) \\ &= \log. a + (10 - \log. b) + \mathrm{L} \sin \alpha + \mathrm{L} \tan \phi + \mathrm{L} \sec \beta - 40 \\ &= \log. a + \text{ar. co. } \log. b + \mathrm{L} \sin \alpha + \mathrm{L} \tan \phi + \mathrm{L} \sec \beta - 40 \end{aligned}$$

Of the same nature as the table of log-sines, log-secants, etc., is the

Table of Log-haversines. The log-haversine of an arc is the same as the "log. of the square of sine of half the arc", and this is sometimes the heading of the table. Since

$$\text{hav}\ \alpha = \sin^2 \frac{\alpha}{2}$$

$$\log.\ \text{hav}\ \alpha = 2 \log.\ \sin \frac{\alpha}{2}$$

$$\text{L hav}\ \alpha - 10 = 2\left(\text{L}\sin \frac{\alpha}{2} - 10\right)$$

$$\therefore \text{L hav}\ \alpha = 2\ \text{L}\sin \frac{\alpha}{2} - 10.$$

2. *Table of Natural Versines.*—This table is used with advantage when an angle or arc is required to the nearest second. It is constructed in such a manner as to render it conveniently available in logarithmic computations. To avoid the introduction of negative characteristics, every versine is multiplied by one million. Example—Vers 60° = $\frac{1}{2}$ = ·5; tab. vers = ·5 × 1,000,000 = 500,000. Here, in the application of logarithms, log. vers 60° = $\bar{1}\cdot698970$, but log. tab. vers 60° = 5·698970. Whenever one of these tabular versines is used in any problem, the result must be corrected for this constant factor of the tables. For an example, see "Auxiliary Angle A." In taking logarithms of tabular versines, the logarithm of 1,000,000 will appear as the correction; for

$$\begin{aligned}
\text{tab. vers}\ \alpha &= \text{vers}\ \alpha \times 1{,}000{,}000 \\
\log.\ \text{tab. vers}\ \alpha &= \log.\ \text{vers}\ \alpha + \log.\ 1{,}000{,}000 \\
&= \log.\ \text{vers}\ \alpha + 6 \\
\therefore \log.\ \text{vers}\ \alpha &= \log.\ \text{tab. vers}\ \alpha - 6.
\end{aligned}$$

Logarithms, Proportional.—Logarithms arranged in tables for finding the fourth term of a proportion, of which the first term (the greatest) is a ant quantity. Let A, *a*, *c*, *x* be the four terms of the proportion of which it is required to find x. Since $x = \frac{ac}{A}$, by common logarithms we have

$$\log. x = \log. a + \log. c - \log. A \quad . \quad . \quad . \quad . \quad (1)$$

Here four inspections of the table are necessary, and one addition and one subtraction are required in the calculation. But instead of a table of common logarithms, a special table may be formed for the constant A, which requires only three inspections and one addition in the calculation. In equation (1), change the signs and add log. A to each side,

$$\therefore \log. A - \log. x = \log. A - \log. a + \log. A - \log. c.$$

Or if we establish the definition—the logarithm of A diminished by the logarithm of any other number less than A is the proportional logarithm of that number—we have

$$\text{prop. log. } x = \text{prop. log. } a + \text{prop. log. } c.$$

Proportional logarithms are used for interpolating in the tables given in the "Nautical Almanac". Thus, let it be required to find the time corresponding to a lunar distance found from an observation: The "Nautical Almanac" gives two distances, with the date of each three hours apart, between which our distance lies. Here $A = 3^h$, $a =$ the interval from the first date to the date of our observation, c the change of distance in 3^h, x the change of distance in the interval a. Then, as we want to find a, we have

$$\text{prop. log. } a = \text{prop. log. } x - \text{prop. log. } c.$$

A table for this particular problem, where $A = 3^h$, is technically called the *Table of Proportional Logarithms;* but there are other tables of precisely the same character, and we shall notice them all together. In the "Nautical Almanac" the sun's right ascension, declination, etc., are given for every 24^h; the moon's semi-diameter, horizontal parallax, etc., are given for every 12^h; the lunar distances are given for every 3^h; and the moon's right ascension and declination for every 1^h. Tables are co structed for each of these cases and inserted in collections of nautical tables under the following titles:—

1. Greenwich Date Logarithm for Sun.

A = 24^h. The logarithm of 1440 (the number of minutes in 24^h), diminished by the logarithm of the number of minutes in any period less than 24^h, is called the "Greenwich date logarithm for sun" for that period.

2. Greenwich Date Logarithm for Moon.

A = 12^h. The logarithm of 720 (the number of minutes in 12^h), diminished by the logarithm of the number of minutes in any period less than 12^h, is called the "Greenwich date logarithm for moon" for that period.

3. Proportional Logarithm.

A = 3^h. The logarithm of 180 (the number of minutes in 3^h), diminished by the logarithm of the number of minutes in any period less than 3^h, is called the "proportional logarithm" for that period.

4. Logistic Logarithm.

A = 1^h. The logarithm of 3600 (the number of seconds in 1^h), diminished by the logarithm of the number of seconds in any period less than 1^h, is called the "logistic logarithm" for that period.

These tables are not now of much practical utility in consequence of the improvement in the "Nautical Almanac".—See **Interpolation.**

"Logarithmic Difference."—Under this heading is tabulated in some works on navigation a quantity used in one of the methods of "clearing the distance" in finding the longitude by a lunar observation. If m and s be the true altitudes of the moon and other body of the observation, m' and s' their apparent altitudes, then

$$\text{“Log. diff.”} = \log. \frac{\cos m \cos s}{\cos m' \cos s'}$$

$$= (\log. \cos m + \log. \cos s) - (\log. \cos m' + \log. \cos s');$$

hence the name. Raper, Table 73.

Longitude (L. *lòngitudo*, “ length ”).—See **Longitude and Latitude.**

Longitude of an Observer.—The longitude of an observer's place on the earth's surface is the arc of the equator intercepted between the first meridian and the meridian of the observer. Or, which is the same thing, the angle at the pole contained between two meridians, the one passing through a fixed conventional place of reference, the other through the station of the observer. Longitude is measured from the first meridian, and is reckoned eastward and westward either in arc from 0 to 180°, or in time from 0 to 12^h. This method, however, gives rise to confusion and ambiguity, and it would be much more systematic and convenient if we were to reckon longitudes invariably westward from their origin round the whole circle from 0 to 360° 0′ 0″ or 0 to $24^h\ 0^m\ 0^s$. Longitude and latitude are the co-ordinates for defining the positions of places on the earth's surface.—See **Longitude and Latitude.**

Longitude in Arc, and Longitude in Time.—The earth rotates uniformly on her axis once in 24 hours, and thus every spot on her surface describes a complete circle, or 360°, in that space of time. Hence the longitude of any place is proportional to the time the earth takes to revolve through the angle between the first meridian and the meridian of the place, and thus the longitude of a place may be expressed either in *arc* or in *time*. In reckoning by arc each degree is divided into 60 minutes, and each minute into 60 seconds. In reckoning by time, each hour is similarly divided into 60 minutes, and each minute into 60 seconds. But a distinct notation for each of these has been adopted, degrees, minutes, and seconds being represented by ° ′ ″, and hours, minutes, an seconds by $^{h\ m\ s}$; and care should be observed not to use the same marks for both, great confusion arising from so doing. Longitude in arc and longitude in time are easily convertible, for since 360° is equivalent to 24^h, 15° is equivalent to 1^h, 1° to 4^m, and 1′ to 4^s.

Longitude (Terrestrial), Circles of.—Great circles of the terrestrial sphere passing through the poles of the equator, and so called because they severally mark out all places which have the same "longitude". They are also, and generally, called "*Meridians*", because for every place on the same circle it is noon simultaneously.—See **Co-ordinates for the Terrestrial Sphere.**

Longitude, Difference of (abbreviated, diff. long.).—The difference of longitude between two places is the arc of the equator intercepted between their meridians.

Longitude, Difference of, in Time.—The difference in longitude between two places as shown by the polar angle between their meridians. This is commonly called the *Meridian Distance*, and is obtained chronometrically by comparing the errors on local mean time shown by a chronometer at the two places in succession. The error, having been determined by observation at the first station, is corrected by the rate of the chronometer for the interval between this and an observation for the error at the second station; so that the difference of the errors on the local mean time gives accurately the difference of longitude in time between the two places, or their "Meridian Distance". The accurate and systematic measurement of meridian distances is of great importance, especially for determining the longitude of places previously unknown or uncertain. The chief difficulty of the problem is how to treat the variations of rate between the two observations, so as to produce uniform and consistent results. The various methods proposed will be found fully discussed in Shadwell's "Notes on the Management of Chronometers and the Measurement of Meridian Distances".

Longitude from.—The longitude of the place sailed from.

Longitude in, or to.—The longitude of the place sailed to.

Longitude, how found.

I.—IN GEO-NAVIGATION.

The latitude and longitude at the preceding noon being given, together with the distance run and the course made good since, and the latitude in having been first found by the aid of the relation True diff. lat. = dist. × cos. course; the "longitude in" may be found—(1) With a table of *Meridional Parts*, which gives the meridional difference of latitude; thence,

$$\begin{aligned} \text{Diff. long.} &= \text{mer. diff. lat.} \times \text{tan course.} \\ \therefore \text{log. } \textit{diff. long.} &= \text{log. mer. diff. lat.} + \text{L tan course} - 10. \end{aligned}$$

Or (2), By "middle-latitude," from the formulæ

$$\left.\begin{aligned} \text{dep.} &= \text{true diff. lat.} \times \text{tan course} \\ \text{diff. long.} &= \text{dep.} \times \text{sec mid. lat.} \end{aligned}\right\}$$

$$\begin{aligned} \therefore \text{log. } \textit{diff. long.} &= \text{log. tr. diff. lat.} + \text{L tan course} \\ &\quad + \text{L sec mid. lat.} - 20. \end{aligned}$$

(2′) By "inspection" from the Traverse Table.

$$\begin{aligned} \text{Since dist.} &= \text{dep.} \times \text{cosec course} \\ \text{diff. long.} &= \text{dep.} \times \text{sec mid. lat.} \\ &= \text{dep.} \times \text{cosec (complement mid. lat.)}; \end{aligned}$$

if the Traverse Table be entered with the given departure and with the complement of the mid. lat. as a course, the distance corresponding will be the diff. long. nearly.

II.—IN CELO-NAVIGATION.

The longitude of a place is measured by the difference between the mean time at the first meridian and the mean time at the place. W

the time at the place is the greater, its longitude is E.; when it is the less, its longitude is W. Hence the problem of finding the longitude resolves itself into two distinct parts:—1st, The determination of the mean time at the station of the observer—the navigator's "ship mean time," which we indicate by the letters S. M. T.; and 2nd, The determination of the mean time at the first meridian as that of Greenwich, which we indicate by the letters G. M. T. Different combinations may be made of the several methods of solving the two parts of the problem.

FIRST PART.—DETERMINATION OF S. M. T.

(I.) **One Altitude.**—The observation of an altitude of a heavenly body enables us, with the assistance of the known latitude, and of the declination and other elements given in the "Nautical Almanac", to compute the hour-angle H from the formula [see **Hour-Angle**].

$$\begin{aligned}\text{L hav H} &= \text{L sec } \delta + \text{L sec } l - 20 + \tfrac{1}{2}\,\text{L hav}\,(z + \overline{l \pm \delta}) \\ &\quad + \tfrac{1}{2}\,\text{L hav}\,(z - \overline{l \pm \delta}).\end{aligned}$$

The body observed may be either—(1) the sun, (2) a star, or a planet, (3) the moon—the moon furnishing the least reliable means of solving the problem.

1. When H is the hour-angle of the *sun*, measured westward from the meridian,

$$\text{S. M. T.} = \text{H} \pm \text{equation of time.}$$

2 and 3. When H is the hour-angle of *any other body but the sun*, the mean time being known approximately, the right ascension of the mean sun may be found by adding, to the sidereal time at the preceding Greenwich mean noon, the acceleration for the Greenwich date. Then,

$$\begin{aligned}\text{S. M. T.} &= \text{ship sidereal time} - \text{R.A. mean sun} \\ &= \text{H} + \text{R.A. body observed} - \text{R.A. mean sun.}\end{aligned}$$

[Before the subtraction of the R.A. mean sun, 24^h must be added to or deducted from the sum H + R.A. body, as the case may require.]

(II.) **Two Altitudes.**—The time at ship for the middle time between two observations for obtaining the latitude ("Double Altitudes") may be found by an extension of Ivory's method proposed by Riddle.—See **Latitude, how found,** (II.) (III.) ii.

SECOND PART.—DETERMINATION OF G. M. T.

There are two distinct methods of finding the G. M. T.

(I.) **By Chronometer.**—The error of the chronometer on G. M. T. at a given date and its rate being known, we thence find the G. M. T. corresponding to the instant when the observation is taken for determining the S. M. T. This is the most convenient and the constant method of finding the longitude at sea.—See **Chronometer.**

(II.) **By Registered Astronomical Phenomena.**—These phenomena take place at the same absolute point of time. Wherever the observer is stationed, the date of their occurrence in G. M. T. is given in the "Nautical Almanac". The principal of such phenomena are—(1) *Lunar Distances*; (2) *Occultations*; and (3) *Eclipses of Jupiter's Satellites.* The only case of this method which is much used at sea is that by lunar distances; it requires no other instrument but the sextant, and when the chronometer is at fault is the chief dependence of the navigator. The longitude may also be determined by finding the increase of the moon's R.A. in the interval between her transit over the first meridian and her transit over the meridian of the observer. This is done by the methods of—(4) *Moon Culminating Stars*; or, (5) The *Moon's Altitude.* The former of these methods requires the use of a transit instrument, and therefore cannot be used at sea. We need not notice it further, referring for the explanation of the principle to the "Nautical Almanac" (Appendix—"Moon Culminating Stars"). The latter of these methods is sometimes used at sea, but, though it may occasionally prove of service, the result is very uncertain. The principle is simply this—From the observed altitude the hour-angle of the moon is computed, and from this, together with the S. M. T., her R.A. is obtained, and then, finally, by interpolation in the ephemeris of the moon's R.A. in the "Nautical Almanac", the G. M. T. corresponding to this R.A. may be found.

We shall now further notice the first three methods mentioned of determining the longitude by finding the G. M. T. from astronomical observations.

1. *Lunar Distances.*—The moon has a very rapid proper motion, sometimes amounting to 15° in 24 hours, and being therefore retarded as regards the diurnal motion nearly an hour on successive days. Her distance, therefore, from the sun, a planet, or bright star which lies in or near to her path, varies very perceptibly in short intervals. The "Nautical Almanac" contains tables of "Lunar Distances" for every third hour of Greenwich mean time, and by interpolation the G. M. T. corresponding to any other intermediate distance of a body tabulated may be found. To determine the longitude at any station on the earth's surface, the observer selects a body whose lunar distance on that day is recorded in the "Nautical Almanac", the preference being given to that body for which the following ratio is the least, $\frac{\text{Dec. of body} \sim \text{Dec. of moon}}{\text{R.A. of body} \sim \text{R.A. of moon}}$; a simple practical guide is to take the prop. log., given in the "Nautical Almanac", which is least, because then the body concerned is altering its distance the fastest. He observes the distance, bringing the image (darkened, if necessary) of the brighter of the two objects to the other. This *observed* distance, by applying the necessary corrections, gives the *apparent* distance. From the apparent, the *true* distance has next to be deduced. This operation is called "Clearing the Distance", and its solution is facilitated by various devices.—See **Lunar Distance, Clearing.**

The true distance being thus obtained, recourse is had to the "Nautical Almanac", and the G. M. T. corresponding to this distance taken out by the method of interpolation.

For the purpose of clearing the distance, the altitudes of the two bodies have to be obtained. This is done in one of two ways. (1) The altitudes may be observed, at the same moment as the distance, by two assistant observers, and in this case one of the altitudes may be utilized for determining the S. M. T. (2) If more convenient, the altitudes may be computed, the S. M. T. being supposed to be known, the error of chronometer on S. M. T. having been ascertained by some independent observation. This computation may be conducted thus:—If H be the hour-angle of the body, δ its declination, and l the latitude; then

$$\text{vers } z = \text{vers } (l \mp \delta) + \text{vers } \theta$$

$$\text{when vers } \theta = 2 \cos l \cos \delta \sin^2 \frac{\text{H}}{2}$$

$$\text{log. tab vers } \theta - 6 = \text{log. } 2 + \text{L} \cos l - 10 + \text{L} \cos \delta - 10 + \text{L hav H} - 10.$$

$$\text{or log. tab. vers } \theta = 6{\cdot}301030 + \text{L} \cos l + \text{L} \cos \delta + \text{L hav H} - 30.$$

$$\text{and log. tab. vers } z = \text{tab. vers } (l \mp \delta) + \text{tab. vers } \theta.$$

A simpler method is to use the formula

$$\text{vers } \theta = \cos l \cos \delta \text{ vers H}$$

$$\therefore \text{ hav } \theta = \cos l \cos \delta \text{ hav H}$$

From the zenith distance z thus found, the true altitude a is known, and hence the apparent altitude a' (which is also wanted) is deduced by inverting the corrections for parallax and refraction.

2. *Occultations.*—The moon in her monthly revolutions round the earth passes over every star or other body lying in her path. The *immersion* of the star behind the body of the moon and its *emersion* are instantaneous, and can be ascertained without the use of any instrument liable to error. These phenomena, therefore, afford a very accurate means of determining the longitude. The method may be used at sea, the observation being effected by means of a common spy-glass. The motion of the ship may prevent the telescope being kept steadily directed to the moon, but the consequent error in noticing the instant of occultation will generally be inconsiderable. An *immersion*, when the *eastern* limb is dark, will be the case most easily and distinctly observable. The calculations, however, are long and tedious.—See Mr. Woolhouse's paper in " Appendix to Nautical Almanac ", 1836.

3. *Eclipses of Jupiter's Satellites.*—The frequency with which these

eclipses recur and the easiness of the observation render this method usually available on shore. The diagrams of the positions of the planet and its satellites, as seen in N. latitude, and other necessary information, are given in the "Nautical Almanac". These figures must be reversed in S. latitude. In taking the observation the following points should be borne in mind:—The telescope should have a magnifying power of not less than 40. The sun should not be less than 8° below the horizon, and Jupiter not less than 8° above it. The observer should be ready some minutes before the time the phenomenon occurs, which may be found roughly by applying the longitude by account to the time given in the "Nautical Almanac". When Jupiter comes to the meridian before midnight, the whole eclipse, both immersion and emersion, takes place on the east side of the planet; when after midnight, on the west side. An inverting telescope reverses this. The first satellite is preferable to the others by reason of the greater rapidity of its motion.

This method of determining the longitude is not very accurate. The clearness of the air, and the power and aperture of the telescope, affect the time of the phenomenon; and the eclipse is not instantaneous, the satellite having a considerable apparent diameter as seen from the planet's centre and the penumbra extending to a sensible, though small, distance beyond the shadow. The only case in which the observation may be considered complete is, when the immersion and emersion of the same satellite are observed on the same evening with the same telescope and by the same person. The mean of the two results will then give the precise instant of the satellite's opposition to the sun. The method is not practised at sea, in consequence of the difficulty in directing the telescope steadily.

Longitude of a Heavenly Body.—The arc of the ecliptic intercepted between the first point of Aries and the secondary circle to the ecliptic, which passes through the place of the body.. Or, which is the same thing, the angle at the pole of the ecliptic between the circle of longitude passing through the first point of Aries and that passing through the place of the body. Longitude is reckoned from the first point of Aries eastwardly (in conformity with the direct motions of the heavenly bodies) from 0 to 360°. Longitude and latitude are the ecliptic co-ordinates for defining the positions of points on the celestial concave, and indicating their positions relatively to each other.—See **Longitude and Latitude.**

Longitude (Celestial), Circles of.—Great circles of the celestial concave passing through the poles of the ecliptic, and so called because they severally mark out all points which have the same "longitude". They are also called "*Circles of Latitude*", because latitudes are measured upon them.—See **Co-ordinates for the Surface of a Sphere.**

Longitude, Heliocentric and Geocentric, of a planet.—See under **Latitude.**

Longitude and Latitude (L. *longitudo*, "length"; *latitudo*, "breadth").—Co-ordinates to define the position of a point on a sphere. The extent of a sphere, measuring along a great circle, may be truly distinguished as the "*length*", in contrast with the extent measured from this circle either way to its two poles, the "*breadth*", the magnitude of the former being double the whole of the latter. But these terms are technically used with reference to a particular great circle, and differently of the two spherical surfaces with which the navigator and astronomer are concerned. (1) With respect to the *earth*, that great circle is chosen whose plane is perpendicular to the axis of rotation—the *Equator*. Taking into account further that the earth is not truly a sphere, but an oblate spheroid, the equator divides it into two uniform parts, and to it all points on the surface hold a similar relation. (2) With respect to the *heavens*, the apparent path of the sun naturally suggests itself as the great circle of reference, and so "length" of the heavens is reckoned along the *Ecliptic*, and the "breadth" perpendicular to it. To this great circle the other moving heavenly bodies preserve the most uniform relations. It is very unfortunate that the same nomenclature should be in use in geography and uranography. Part of the difficulty thence arising may be avoided in the case before us by always bearing in mind the meaning of the words "longitude" and "latitude", and that with express reference to the terrestrial spheroid and the celestial concave separately. We must be very careful how we conceive a connection between the circles of the terrestrial and those of the celestial sphere. Though there may be some correspondence or analogy, there is not that connection that at first sight appears. And hence it would be well if we could avoid describing these circles by the same word, even though this be qualified with the adjectives "terrestrial" and "celestial"; thus we could wish that the phrases "terrestrial equator" and "celestial equator" fell into disuse, and were superseded by the simple words "Equator" and "Equinoctial". These answer to each other as do the "meridians" and "circles of declination", but there is no *connection* between them. If we imagine the plane of the equator and that of the several meridians, these being all *fixed* circles of the earth, to be extended till they cut the celestial concave, the great circles in which they intersect it will *not* be fixed circles of the heavens, but revolve or sweep over its face diurnally. The great circle corresponding to the equator (in which it must be remembered is situated the origin of the ordinates reckoned on it) would revolve in its own plane, and the great circles corresponding to the meridians would move perpendicularly to their own planes with the daily rotation of the earth. It is evident, then, that the position of a point in the heavens cannot be defined by referring it to such great circles. But great circles may be conceived for this purpose analogous to the above, but differing from them in this—that they remain stationary and fixed in the heavens, quite independent, therefore, of the geographical position of the observer. The great circle of the heavens which thus answers to the equator on the earth is called the equinoctial; and the great circles of the heavens perpendicular to it, and answering therefore to meridians of the earth, are called circles of declination. Arcs of these circles used as coordinates to define the position of a point in the heavens, are very properly not called by the same names (longitude and latitude) as those which designate arcs on the corresponding circles on the earth's surface, but have the distinctive terms applied to them of "right ascension" and "declination". This is well; but worse confusion has been introduced by the early astronomers using the terms "longitude" and "latitude", already appropriated by the geographer, and that to describe arcs of altogether another system of co-ordinates of the heavens. Their reason for their choice of these words is explained above; but the unlucky device is a source of difficulty to the young student and of inconvenience to all. Sir John F. W. Herschel, after speaking of the terms in their terrestrial sense, says on this point: "It is now too late to remedy this confusion, which is engrafted into every existing work on astronomy. We can only regret, and warn the reader of it, that he may be on his guard when we shall have occasion to define and use the terms in their *celestial sense*, at the same time urgently recommending to future writers the adoption of others in their places." The necessity of combining, for the moment, terrestrial and celestial great circle co-ordinates is met by the device of a system of polar co-ordinates, all the elements of which have reference to time. The initial line is the "celestial meridian" (or "noon-circle"), the radius vector is the "hour-circle", and the polar angle the "hour-angle".—See **Co-ordinates for the Surface of a Sphere**; and **Triangle, Instantaneous.**

Longitude and Latitude (Terrestrial).—Co-ordinates for defining the positions of places on the earth's surface. Longitude is measured on the equator from the intersection of it by the first meridian, and is generally reckoned eastward and westward from 0 to 180°; latitude is measured on the meridians from the equator to the north and to the south poles from 0 to 90°.—See **Co-ordinates for the Terrestrial Sphere.**

Longitude and Latitude (Celestial).—The ecliptic co-ordinates for defining the positions of points of the celestial concave, and indicating them relatively to each other. Longitude is measured on the ecliptic from the first point of Aries eastward from 0 to 360°; latitude is measured on circles of latitude from the ecliptic both ways from 0 to 90°.—See **Co-ordinates for the Celestial Sphere.**

Loxodromic Curve (λοξὸς, "slanting"; δρόμος, "course").—A curve on the earth's surface which makes a constant angle or slant to the meridian. The same as the "*Equiangular Spiral*" or "*Rhumb Line*".

Lubber's Point.—The mark on the inside of the compass-case indicating the direction of the ship's head. When the box containing the compass is properly fixed in its place, the line joining the centre of the compass-card and the lubber's point is fore-and-aft, or parallel to the keel of the ship. The derivation of this compound word is frequently a subject of discussion. The expression is generally connected with "land-lubber", the contemptuous name seamen use for any awkward clumsy fellow without intelligence or activity. Such a one would slavishly require the aid of this point in steering, whereas a helmsman who was a seaman would more truly strike a fore-and-aft line with his eye; just as in going aloft the former would require the "lubber's hole", while the latter would mount by the futtock-shrouds. It is best, however, to fall back, for its significance, upon what is doubtless the root of the word. To "lob" is found in Shakespeare, meaning "to let fall heavily", and the old English "lob", Welsh "llob", means "a dull sluggish person". Probably the "lubber's point" was originally called the "*lob-point*". In the earliest azimuth compasses, there were four of these small black lines, corresponding to the quadrantal divisions of the circle, which remained fixed with the ship, while the compass-card appeared to move in a lively manner. This card was then significantly called the "Fly".—See **Compass, Steering.**

Lunar (L. *luna*, "the moon").—Pertaining to the moon. Thus we have the *Lunar Month*, the *Lunar Day*—portions of time defined by the motions of the moon; *Lunar Eclipses, Lunar Distances*, etc.

Lunar Distances.—The moon having a very rapid proper motion, her distance from other bodies which lie in her path varies very perceptibly in short intervals. Hence these distances have been made the foundation of one of the most important methods of determining the longitude at sea. [See **Longitude.**] In the "Nautical Almanac" are registered for every third hour of Greenwich mean time the angular distances of the moon's centre from certain bodies, such as they would appear to an observer at the centre of the earth. When a lunar distance has been observed at any station on the surface of the earth, and reduced to the centre by clearing it of the effects of parallax and refraction, the Greenwich mean time corresponding to this true distance can be found from the tables by the method of interpolation.

In observing a distance, the general rule is—Bring the image (darkened by shades, if necessary) of the brighter of the two to the other object seen directly.

Lunar-Distance Bodies.—Bodies whose distances from the moon are calculated beforehand and tabulated in the "Nautical Almanac", pp. XIII.–XVIII., of each month for the determination of the longitude. They are fourteen in number, viz.: the sun, four planets, and nine fixed stars.

1. The inclination of the moon's orbit to that of the earth is about 5° 9′; hence, the moon's latitude never exceeds this amount N. or S., and, although her actual path in the heavens is a very irregular curve, she is always to be found within a belt of about 10° 18′ broad which is bisected longitudinally by the ecliptic. Of the four planets used in lunars, the path of Venus has the greatest inclination to the ecliptic, viz.: about 3° 24′; hence all these bodies, also, are found always within this belt. It was a belt of this kind, 8° or 9° on each side of the ecliptic, that was called by the ancient astronomers the Zodiac.—See **Zodiac.**

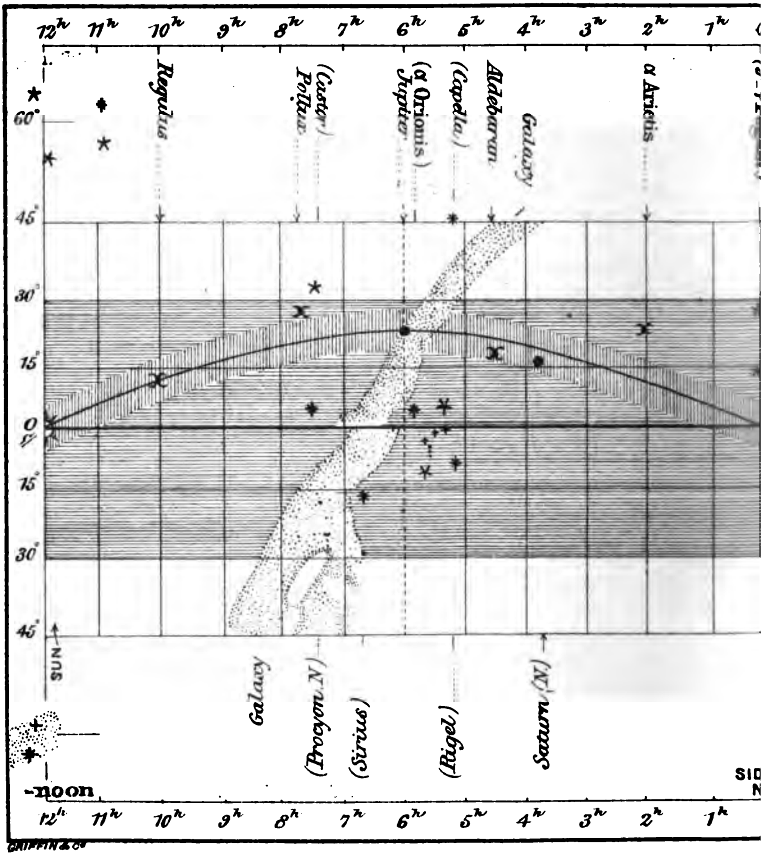
Referring the sun, moon, and planets to the equinoctial. The obliquity of the ecliptic being about 23° 28′, the sun is always found in a zone, 46° 56′ broad, bounded by the tropics; the moon is always found in a zone, 57° 14′ broad, bounded N. and S. by the parallels of declination 28° 37′ (23° 28° + 5° 9′); and the four planets are also well within the same zone. Of the fixed stars used in lunars only one, Fomalhaut, has a declination slightly exceeding 30°. We may therefore consider that all the lunar-distance bodies are comprised within an equatorial zone 60° broad.

In the accompanying chart we have given the regions of the heavens from the equinoctial to 45° N. and to 45° S. declination, thus comprehending a zone of 90° broad. The lunar-distance zone of 60° broad is shaded horizontally; and in this the ecliptic is drawn with its accompanying lunar and planetary belt of about 10° broad, shaded vertically.

2. The motions in right ascension of the sun, moon, and planets are all subject to irregularities; but the change in the moon's right ascension is much more rapid than that of any of the other bodies that have a proper motion. Hence the admissibility of the sun and planets as lunar-distance bodies. A general idea of the ratio of the motion of the moon to that of the sun will be best obtained by comparing their sidereal periods. The moon completes a revolution of the celestial concave in a Sidereal Lunar *Month,* the mean length of which is 27·322 mean solar days; the sun completes a revolution of the celestial concave in a Sidereal *Year,* the mean length of which is 365·256 days. The proper motion of the moon in the heavens is therefore about 13⅓ times more rapid than that of the sun. To guard against confusion it is important that the student should remark that a complete sidereal revolution is here called in the case of the sun a "year", and in the case of the moon a "month".

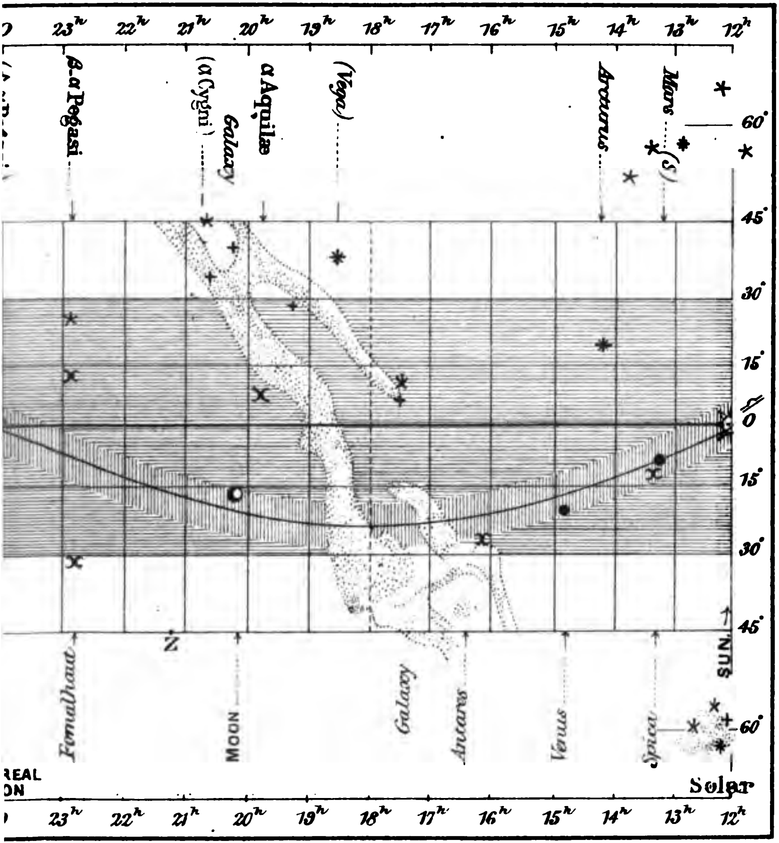
In the chart we have inserted the sun, ⊙, in the autumnal equinox (♎ R.A. 12^h), and placed the moon and the planets in their proper positions for this date, September 22nd, 1882. The moon, ○, is two days after her first quarter in R.A. a little after 20^h and declination about S. 15°. The planets, o, are placed according to their positions for September 22nd, 1882, given in the following table:—

STAR CHART FOR



✱ Stars of 1st Magnitude ✶ Stars of 2nd Mag: + St

LUNAR DISTANCES.



PORTSMOUTH

s of 3rd Mag: ● or ○ Planets ✕ Lunar Distance Stars.

		Symbol.	Inclination of orbit.	R.A.	Dec.
Inferior Planet ...	Venus	♀	... 3° 23′	... 14^h 52^m	... − 19° 42′
Superior Planets	Mars	♂	... 1° 51′	... 13^h 26^m	... − 8° 50′
	Jupiter	♃	... 1° 19′	... 6^h 1^m	... + 22° 59′
	Saturn	♄	... 2° 30′	... 3^h 37^m	... + 16° 58′

3. *Fixed Stars.*—The fixed stars used as lunar-distance bodies are the nine, particulars of which are given in the following table. They are inserted in the chart and distinguished by the symbol)(.

	Mag.	R.A.		Dec.
1. (*Hamel*) α Arietis	... 2 ...	2^h 0^m 36^s ...	+	22° 54′ 32″
2. *Aldebaran* (α Tauri)	... 1 ...	4^h 29^m 13^s ...	+	16° 16′ 21″
3. *Pollux* (β Geminorum)	1.2 ...	7^h 38^m 9^s ...	+	28° 18′ 22″
4. *Regulus* (α Leonis)	... 1.2 ...	10^h 2^m 7^s ...	+	12° 32′ 22″
5. *Spica* (α Virginis)	... 1 ...	13^h 19^m 1^s ...	−	10° 32′ 52″
6. *Antares* (α Scorpii)	... 1.2 ...	16^h 22^m 13^s ...	−	26° 10′ 11″
7. (*Altair*) α Aquilæ	... 1.2 ...	19^h 45^m 5^s ...	+	8° 33′ 51″
8. *Fomalhaut* (α Piscis Australis)	1.2 ...	22^h 51^m 12^s ...	−	30° 14′ 26″
9. (*Markab*) α Pegasi	... 2	... 22^h 58^m 57^s ...	+	14 34′ 44″

We have not complicated the chart, introduced to illustrate lunar-distance bodies, by crowding it with many other stars. All stars however of the first magnitude, within declinations 45° N. and 45° S., are inserted, and a few constellations useful as position-guides are given, the names being in brackets. The most useful of these, in the equatorial regions, are Pegasus and Orion. The Galaxy is also depicted as being a useful natural guide on a bright night.

4. With reference to Diurnal Time the zero circle of right ascensior

O♈O is coincident with the meridian of Greenwich at sidereal noon at Greenwich. On the date represented in the chart, solar time at Greenwich is midnight: and Z will represent the zenith of a place in latitude 45° S. and longitude 40° W., the time at this place being between 9^h and 10^h P.M. The bodies given in the "Nautical Almanac" for this date, with their distances are:—

Antares	...	...	W	53°	29′	41″
Fomalhaut	...	...	E	40°	12′	5″
α Pegasi	...	...	E	51°	44′	43″
α Arietis	...	...	E	94°	14′	47″

The chart accompanying this article is necessarily on a very small scale, and is intended only for explanation. The young officer is strongly advised to draw a chart on a larger scale, and himself insert the different bodies, the fixed stars being put in in ink and the other bodies in lead pencil. On such a chart he may also approximately project his zenith. If it is objected that this will not suffice for a problem in the practical solution of which extreme accuracy is essential, we would urge that a rough solution is frequently invaluable both as an aid for grasping the principle and as a safeguard against any fundamental error being introduced by an oversight.

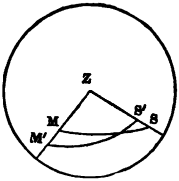
Lunar Distance, Clearing the.—The operation of deducing the *true* from the *apparent* lunar distance. This problem is effected by the solution of two spherical triangles having a coincident angle subtended by the two distances. The three sides of one of these triangles being given, this angle may be found; then in the other triangle, two sides and the included angle are known to determine the third side, the true distance required.

Let M and M′ be the true and apparent places of the moon.
S „ S′ „ „ places of the other body.
m „ m' „ „ altitudes of the moon.
s „ s' „ „ altitudes of the other body.
d „ d' „ „ distances.
z the true zenith distance of the moon.
v „ „ other body.

In the triangle M′ZS′

$$\cos^2\frac{Z}{2} = \frac{\cos S \cos (S - d')}{\cos m' \cos s'}$$

$$\text{Where, } S = \frac{m' + s' + d'}{2}$$



Again, in the triangle MZS

$$\sin\frac{d}{2} = \sqrt{\cos\left(\frac{m+s}{2} + \theta\right)\cos\left(\frac{m+s}{2} - \theta\right)}$$

$$\text{Where, } \sin\theta = \sqrt{\cos m \cos s \cos^2\frac{Z}{2}}$$

1. The above formulæ require only the ordinary tables of log sines and log cosines. The calculation may be facilitated by the adoption of the following artifice:—Take m', s', and d' to the nearest minute or half minute, rejecting the odd seconds, and the logarithms required can then be taken out by inspection exactly from the tables. Afterwards increase m and s by as many seconds as have been rejected from m' and s', and add to d the seconds reserved from d'.

2. The work is much facilitated by the use of special tables giving the value of a subsidiary angle for different arguments.

In the preceding formulæ combine the expressions for sin θ and $\cos^2 \frac{Z}{2}$ thus—

$$\text{Sin}\ \theta = \sqrt{\frac{\cos m \cos s}{\cos m' \cos s'} \cos S \cos (S - d')}$$

$$\text{Where, } \log \frac{\cos m \cos s}{\cos m' \cos s'} = \text{“Logarithmic Difference”} = \log (2 \cos A).$$

(*a*) The “Logarithmic Difference” is given in Raper's Tables, and may be used with the ordinary tables of log sines and log cosines.—See **Logarithmic Difference.**

(*b*) The “Auxiliary Angle” (A) is given in Inman's Tables, and may be used very conveniently in conjunction with a table of versines. The formula embodying the operation is—

$$\begin{aligned}\text{Tab vers } d = \text{tab vers } (z + v) + \text{tab vers } (d' + A) + \text{tab vers } (d' \sim A) \\ + \text{tab vers } (\overline{m' + s'} + A) + \text{tab vers } (\overline{m' + s'} \sim A) - 4{,}000{,}000.\end{aligned}$$

In reducing this formula, since the true distance can never differ from the apparent distance by more than about a degree, it will suffice to take out the last five figures of the versines *only*, and, rejecting the tens, look out for the true distance in that part of the table corresponding to the degree of the apparent distance.—See **Auxiliary Angle, A.**

3. Airy's Method.—A method of clearing the distance has lately been devised by Sir G. B. Airy depending on the use, in the factors of corrections, not of each apparent element nor of the corresponding corrected element, but of the mean between the two.

The elements which we require are: the apparent altitude and the corrected altitude of the moon, the apparent and the corrected altitude of the sun, and the apparent and corrected distance. The first five of these are known accurately. The last (the corrected distance between the sun and the moon) must be estimated. There is no difficulty in doing this, with accuracy abundantly sufficient for this investigation. With

Greenwich time by account, the distance may be rudely computed from the distances in the "Nautical Almanac". Or without time or calculation, a navigator accustomed to lunar distances may form a shrewd guess of the probable amount of correction. We have now all the six elements required for the investigation.

Let Moon's corrected altitude + moon's apparent altitude = 2 A;
Moon's corrected altitude − moon's apparent altitude = 2 a;
Sun's apparent altitude + sun's corrected altitude = 2 B;
Sun's apparent altitude − sun's corrected altitude = 2 b;
Corrected distance + apparent distance = 2 C;
Corrected distance − apparent distance = 2 c.

Then, Moon's apparent altitude = A − a; corrected altitude = A + a
Sun's apparent altitude = B + b; corrected altitude = B − b;
Apparent distance = C − c; corrected distance = C + c.

The essential circumstance which directs the further investigation is the equality of the zenithal angles, and consequently of the cosines of the zenithal angles. The corresponding equation is—

$$\frac{\text{Cos}\,(C - c) - \sin\,(A - a)\,.\,\sin\,(B + b)}{\cos\,(A - a)\,.\,\cos\,(B + b)} = \frac{\text{Cos}\,(C + c) - \sin\,(A + a)\,.\,\sin\,(B - b)}{\cos\,(A + a)\,.\,\cos\,(B - b).} \quad . \quad . \quad . \quad . \quad \text{(i.)}$$

This equation may be reduced and simplified by neglecting terms which do not affect the practical accuracy of the result. It thus becomes—

$$\left.\begin{cases} + \cos A\,.\,\cos B\,.\,\sin C \times 2c \\ - \sin A\,.\,\cos B\,.\,\cos C \times 2a + \cos A\,.\,\sin B\,.\,\cos C \times 2b \\ - \sin A\,.\,\cos A \times 2b + \sin B\,.\,\cos B \times 2a \end{cases}\right\} = 0 \quad \text{(iii.)}$$

Remarking that $2a$, $2b$, $2c$ are the corrections of moon's altitude, sun's altitude, and distance; the result of the equation is—

$$\text{Correction of distance}\left\{\begin{array}{c}(+\tan A\,.\,\text{cotan}\,C-\sec A\,.\,\sin B\,.\,\text{cosec}\,C)\\ \times\ \text{correction of moon's altitude}\\ (-\tan B\,.\,\text{cotan}\,C+\sin A\,.\,\sec B\,.\,\text{cosec}\,C)\\ \times\ \text{correction of sun's altitude}\end{array}\right\}\ \text{(iv.)}$$

The only opening to error in this formula is in the estimated value of C, as depending on error in the estimated "Nautical Almanac" distance, or in the estimated correction to the observed distance. Suppose that the time by account was 4^m in error (implying error of 1° in longitude). The approximate correction of distance would be taken out about 2′ in error, and C would be about 1′ in error. If the value of the distance was about 60°, an error of 1′ would produce in cotan C an error of about $\frac{1}{1400}$ of that term of the computed correction, and in cosec C the error would be $\frac{1}{6000}$. These would be hardly sensible. But if with C corrected by this approximation, the calculation be repeated (requiring only a few minutes), the error of result will be totally insensible.

The above is extracted from Airy's brochure, published by order of the Lords Commissioners of the Admiralty. The form proper to be used in working examples by this method is appended; and as the method is new and, we believe, destined eventually to supersede all others, we subjoin the form, with the directions.

(iv.) Prepare this Table, inserting numbers instead of the printed words.

Correction to Moon's Apparent Altitude (additive).	Correction to Sun's Apparent Altitude (subtractive).	First Approximaton.	Second Approximation (if necessary).
Moon's Apparent Altitude. Moon's Corrected Altitude. Sum A = Half Sum	Sun's Apparent Altitude. Sun's Corrected Altitude. Sum B = Half Sum	Assumed Correction to Apparent Distance (additive) (subtractive). Apparent Distance. Corrected Distance. Sum C = Half Sum	Assumed Correction to Apparent Distance (additive) (substractive). Apparent Distance. Corrected Distanee. Sum C = Half Sum

Then proceed with the following calculations, using 5-figure-logarithms—

First Approximation.	Second Approximation if necessary).
Additive Terms.	Additive Terms.
Log tan A........................	(Repeat) Log tan A ....
Log cotan C	Log cotan C..........................
Log corr. to Moon's Alt ...	(Repeat) Log corr. to Moon's Alt.
Sum and Number ...	Sum and Number.........
Log sine A	(Repeat) Log sine A..............
Log secant B	(Repeat) Log secant B ....
Log cosecant C	Log cosecant C ....
Log correction to Sun's Alt.	(Repeat) Log corr. to Sun's Alt..
Sum and Number ...	Sum and Number.........
Sum of Additive Terms	Sum of Additive Terms ......
Subtractive Terms.	Subtractive Terms.
Log secant A	(Repeat) Log secant A ....
Log sine B	(Repeat) Log sine B ....
Log cosecant C.................	Log cosecant C ....
Log corr. to Moon's Alt. ...	(Repeat) Log corr. to Moon's Alt.
Sum and Number ...	Sum and Number...........
Log tan B	(Repeat) Log tan B ....
Log cotan C	Log cotan C ....
Log correction to Sun's Alt.	(Repeat) Log corr. to Sun's Alt..
Sum and Number ...	Sum and Number...........
Sum of Subtractive Terms	Sum of Subtractive Terms ...
Combination of Additive and Subtractive = Correction to Apparent Distance	Combination of Additive and Subtractive = Correction to Apparent Distance ....

This form supposes that C is less than 90°. When C exceeds 90°, the supplement to 180° is to be taken, the cosecant and cotangent of that supplement are to be used, and the signs of the first and fourth numbers, which are produced by cotan C, are to be changed; the first number will become subtractive, and the fourth number additive.

The second approximation will very rarely be required. If, however, the final "Correction to Apparent Distance" differ from that assumed at the beginning by 2′ or 3′, it may be satisfactory to use the second approximation; it is very easy.

Airy gives a method of reducing the original equation which many not well versed in trigonometry may perhaps find the most simple; but others may be more familiar with and therefore prefer the application of the formulæ for multiplication of angles. We therefore subjoin the following reduction of the equation:—

$$\frac{\text{Cos}\,(\text{C} - c) - \sin(\text{A} - a)\,.\,\sin(\text{B} + b)}{\cos(\text{A} - a)\,.\,\cos(\text{B} + b)} = \frac{\text{Cos}\,(\text{C} + c) - \sin(\text{A} + a)\,.\,\sin(\text{B} - b)}{\cos(\text{A} + a)\,.\,\cos(\text{B} - b)} \quad \ldots \quad \text{(i.)}$$

Multiplying up and expanding cos $(\text{C} - c)$ and cos $(\text{C} + c)$. placing the terms involving sin C . sin c on the left hand side, and all the others on the right hand side, we get—

$$\begin{aligned}\text{Sin C}\,.\,\sin c\,.\,&\{\cos(\text{A} + a)\,.\,\cos(\text{B} - b) + \cos(\text{A} - a)\,.\,\cos(\text{B} + b)\}\\ &= \cos\text{C}\,.\,\cos c\,.\,\{\cos(\text{A} - a)\,.\,\cos(\text{B} + b) - \cos(\text{A} + a)\,.\,\cos(\text{B} - b)\}\\ &\quad + \sin(\text{A} - a)\,.\,\cos(\text{A} + a)\,.\,\sin(\text{B} + b)\,.\,\cos(\text{B} - b)\\ &\quad - \sin(\text{A} + a)\,.\,\cos(\text{A} - a)\,.\,\sin(\text{B} - b)\,.\,\cos(\text{B} + b)\end{aligned}$$

or, $\sin\text{C}\,.\,\sin c \times (\mathbf{M}) = \cos\text{C}\,.\,\cos c \times (\mathbf{N}) + \mathbf{N}'$ . . . . . . (1)

$$\begin{aligned}\mathbf{M} &= \cos(\text{A} + a)\,.\,\cos(\text{B} - b) + \cos(\text{A} - a)\,.\,\cos(\text{B} + b)\\ &= \tfrac{1}{2}\cos(\overline{\text{A} + \text{B}} + \overline{a - b}) + \tfrac{1}{2}\cos(\overline{\text{A} - \text{B}} + \overline{a + b})\\ &\quad + \tfrac{1}{2}\cos(\overline{\text{A} + \text{B}} - \overline{a - b}) + \tfrac{1}{2}\cos(\overline{\text{A} - \text{B}} - \overline{a + b})\\ &= \cos(\text{A} + \text{B})\,.\,\cos(a - b) + \cos\overline{(\text{A} - \text{B})}\,.\,\cos(a + b)\\ &= \cos\text{A}\,.\,\cos\text{B}\,.\,(\cos\overline{a - b} + \cos\overline{a + b})\\ &\quad - \sin\text{A}\,.\,\sin\text{B}\,.\,(\cos\overline{a - b} - \cos\overline{a + b})\\ &= 2\cos\text{A}\,.\,\cos\text{B}\,.\,\cos a\,.\,\cos b - 2\sin\text{A}\,.\,\sin\text{B}\,.\,\sin a\,.\,\sin b\,.\end{aligned}$$

$$\begin{aligned}\mathbf{N} &= \cos(\text{A} - a)\,.\,\cos(\text{B} + b) - \cos(\text{A} + a)\,.\,\cos(\text{B} - b)\\ &= \tfrac{1}{2}\cos(\overline{\text{A} + \text{B}} - \overline{a - b}) + \tfrac{1}{2}\cos(\overline{\text{A} - \text{B}} - \overline{a + b})\\ &\quad - \tfrac{1}{2}\cos(\overline{\text{A} + \text{B}} + \overline{a - b}) - \tfrac{1}{2}\cos(\overline{\text{A} - \text{B}} + \overline{a + b})\end{aligned}$$

$$\begin{aligned}
&= \sin(A + B) \,.\, \sin(a - b) + \sin(A - B) \,.\, \sin(a + b)\\
&= \sin A \,.\, \cos B \,.\, (\sin \overline{a - b}) + \sin \overline{a + b})\\
&\quad - \sin B \,.\, \cos A \,.\, (\sin \overline{a + b} - \sin \overline{a - b})\\
&= 2 \sin A \,.\, \cos B \,.\, \sin a \,.\, \cos b \,.\, - 2 \cos A \,.\, \sin B \,.\, \cos a \,.\, \sin b \,.
\end{aligned}$$

$$\begin{aligned}
N' &= \sin(A - a) \,.\, \cos(A + a) \,.\, \sin(B + b) \cos \,.\, (B - b)\\
&\quad - \sin(A + a) \,.\, \cos(A - a) \,.\, \sin(B - b) \,.\, \cos(B + b)\\
&= \tfrac{1}{4}(\sin 2A - \sin 2a)(\sin 2B + \sin 2b)\\
&\quad - \tfrac{1}{4}(\sin 2A + \sin 2a)(\sin 2B - \sin 2b)\\
&= \frac{1}{4}\left\{\begin{array}{l}
\sin 2A \,.\, \sin 2B + \sin 2A \,.\, \sin 2b\\
- \sin 2B \,.\, \sin 2a - \sin 2a \,.\, \sin 2b\\
- \sin 2A \,.\, \sin 2B + \sin 2A \,.\, \sin 2b\\
- \sin 2B \,.\, \sin 2a + \sin 2a \,.\, \sin \,.\, 2b
\end{array}\right.\\
&= \tfrac{1}{2} \sin 2A \,.\, \sin 2b - \tfrac{1}{2} \sin 2B \,.\, \sin 2a\\
&= 2 \sin A \,.\, \cos A \,.\, \sin b \,.\, \cos b - 2 \sin B \,.\, \cos B \,.\, \sin a \,.\, \cos a
\end{aligned}$$

Substituting these values in (1), we get—

$$\left.\begin{array}{l}
2 \cos A \,.\, \cos B \,.\, \sin C \,.\, \cos a \,.\, \cos b \,.\, \sin c\\
- 2 \sin A \,.\, \sin B \,.\, \sin C \,.\, \sin a \,.\, \sin b \,.\, \sin c
\end{array}\right\}
= \left\{\begin{array}{l}
2 \sin A \,.\, \cos B \,.\, \cos C \,.\, \sin a \,.\, \cos b \,.\, \cos c\\
- 2 \cos A \,.\, \sin B \,.\, \cos C \,.\, \cos a \,.\, \sin b \,.\, \cos c\\
+ 2 \sin A \,.\, \cos A \,.\, \sin b \,.\, \cos b\\
- 2 \sin B \,.\, \cos B \,.\, \sin a \,.\, \cos a
\end{array}\right\} \,.\,.\, \text{(ii.)}$$

This equation is the same as that obtained by Airy. He then considers what simplification this rigorously accurate equation will admit, preserving the character of practical accuracy of the highest order.

a, which is half the correction of the moon's altitude, can never exceed 30′. Cos a can never differ from 1 by $\frac{1}{20000}$ part, and $\frac{\sin a}{a}$ can never differ from 1 by $\frac{1}{80000}$ part; and therefore for cos a and sin a we may put 1 and a. The same applies to b and c. In the product sin a . sin b . sin c the factor of sin c can rarely or never amount to $\frac{1}{50000}$ part, and that term may be neglected. The equation is thus reduced to the form (iii.) given, page 231.

Lunar Observation.—The " Lunar Observation " is the name by which is distinguished the important observation of a lunar distance for determining the longitude.

Lunation.—The "*Lunar Month*", or, as astronomers call it, the "*Moon's Synodical Period*". It is determined by the recurrence of the moon's phases, and is reckoned from new moon to new moon—*i.e.* from leaving her conjunction with the sun to her return to conjunction. In consequence of the sun's proper motion in the heavens in the same direction with that of the moon, only slower, the latter body, after leaving the sun, will have more than a complete circle to perform in order to come up to the sun again. Hence a lunation exceeds the moon's sidereal period; its mean length is calculated to be $29^d\ 12^h\ 44^m\ 2{\cdot}87^s$.

Lunitidal Interval.—Of the tides,—the interval between the moon's transit and the high water next following. It varies from day to day during the fortnight between new and full and full and new moon. The lunitidal interval must not be confused with the " Retard " or " Age of the Tide ".

Lyra (L. " The Lyre ").—A constellation to the south of Draco and Cygnus. It contains one bright star *α Lyræ*, also called *Vega*. This may be found by its being situated at about the same distance from the pole star on one side as Capella is on the other, and by its propinquity to the conspicuous pair of the Dragon. Mag. 1; 1882, R.A. $18^h\ 33^m$, Dec. $+ 38° 40.'$

M

m.—Of the letters used to register the state of the weather in the log-book, m indicates "*Misty or Hazy—so as to interrupt the view.*"

Magnet.—Magnets are substances (chiefly iron, in some form) whose particles have assumed a certain condition called *Polarity* connected with definite directions governed by terrestrial influence. A magnet when freely suspended by its centre of gravity spontaneously assumes a definite position relatively to the earth, one end or pole pointing towards the north, and dipping downwards, in northern latitudes, the other end or pole pointing towards the south, and dipping downwards, in southern latitudes. This condition of polarity magnets communicate to like substances having the same tendency, when in their vicinity, by a process called *Induction*, and an attractive power is developed. When two magnets are in propinquity, unlike poles attract each other and like poles repel each other. Magnets are either natural or artificial.

(I.) *Natural Magnets.*—The earth as a whole is the great natural magnet. Some natural ores of iron are susceptible of terrestrial induction, especially one combination, which retains its magnetic polarization tenaciously. It consists of the protoxide and the peroxide of iron with small portions of silica and alumina. As blocks of this substance have lain for ages in the same position with regard to the magnetic line of force of the earth, they have acquired magnetic polarity: they have become natural magnets, and fragments when removed from the stratum in which they are found assume an independent polarity according to the laws of magnetism. This natural magnet is usually of a dark grey hue with a dull metallic lustre, and is found in the iron mines of many countries. It was anciently obtained chiefly from Magnesia in Asia Minor, and hence the word "magnet". Its other names are interesting. The people in Pliny's time called it *ferrum vivum*, "quick iron"; the Chinese know it as *tchu-chy*, "the directing stone"; and similarly in the Swedish it is *segel-sten*, "the seeing stone"; in Icelandic, *leiderstein*, "the leading stone"; and in English the *loadstone* or *lodestone* (from Sax. *læden*, "to lead"). Many gems also, and the metals cobalt and nickel, give signs of magnetism.

(II.) *Artificial Magnets.*—Bars of steel to which magnetic polarity has been communicated by artificial means. Iron is technically distinguished as "soft" and "hard" iron according to its magnetic qualities. "Soft iron" becomes instantaneously magnetised by induction when exposed to any magnetic influence, but has no power of retaining any permanent independent magnetism; "hard iron" is less susceptible of being magnetised by induction, but when once magnetised retains its magnetism permanently. "Hard iron" may, however, be of variable hardness, and no uniform standard of magnetic power can be ascribed to it, nor do we always know whether we have really "hard" iron. The description of hard iron, known as "steel", is employed to make artificial magnets. Steel is iron with a definite amount of carbon combined with it, and it may be made almost of one uniform kind; consequently, by its use we obtain magnets the permanency of the known power of which is assured and can be trusted. The steel bar magnets, used for correcting compasses, are made of very hard steel, those of Sir William Thomson being of "glass-hardness".

Magnets may be made by three different kinds of methods: by utilizing the magnetic influence of the earth, by the application of another magnet, or by electro magnetism. (*a*) When a bar remains long in the direction of the magnetic meridian and dip, its particles acquire the magnetic polarity; and this process can be hastened by any means which facilitates a change of condition among the particles, such as heating succeeded by sudden cooling, the transmission of an electric discharge, or by percussion. (*b*) Simple juxtaposition, in a line, end to end, with a bar magnet will convert a bar of iron into a magnet. The energy is doubled by the bar being placed between two magnets in a line, conterminous with their opposite poles. The process may be accomplished by the aid of friction, either by drawing one magnet along the whole length of the bar; or by using two magnets in a manner called "double touch," in which the dissimilar ends of the two magnets, held obliquely, are slided from the centre of the bar to its extremities, this being repeated several times. (*c*) A cylinder of iron may be converted into a magnet by passing an electric current through a metallic wire coiled round it at right angles to its axis.

A knowledge of the above facts is important to seamen. On board ship the stanchions, iron spindles, etc., often become magnets (especially in men-of-war, where the vibration is great from the firing of the guns), and then they cause a more permanent deviation of the compass than what they did in their unmagnetised state. Again, it would be possible for a castaway seaman to extemporise a magnet out of a piece of a ramrod by holding it approximately in the position of the line of magnetic force and striking it with several smart blows. [See **Magnetism, Terrestrial.**] And, finally, by bearing in mind the facts of magnetism, those who have the care of the seaman's best though very susceptible friend will know how to preserve his constancy. The same mechanical means which develop magnetism will also destroy it in a bar placed oppositely or transversely to its natural magnetic position. Thus a needle may lose its power by a fall on a hard substance. Again, spare compass-cards should be kept in cases constructed with a view of keeping poles of the same name from being placed together. According to their form, artificial magnets are classed as "bar magnets", "horse-shoe magnets", "compound magnets", etc.; but the most important practical modification is the magnetic needle.

Magnets; Permanent, Transient Sub-permanent.—

(I.) *A permanent* is a *true* magnet which possesses in itself an independent centre of force or system of forces similar to that exerted by the earth; and it does not part with this power. A permanent magnet is composed of "hard iron", a description to which steel belongs.

(II.) *A transient* is an *induced* magnet, one which is dependent for its magnetism upon the proximity of another external magnet, whether this be the earth itself or a true artificial magnet nearer to it. Its magnetism is movable or unfixed, the manifestation of it depending, at any instant, on the position of the bar relatively to the earth or influencing magnet. Such magnets are formed in "soft iron" (wrought and cast iron) not subject to any special violence.

(III.) *A Sub-permanent* is a *temporary true* magnet—one which has the character of a permanent magnet, possessing an independent centre of force or system of forces, but parting with this power after the lapse of some time. This condition takes place in "soft iron" which, while under the influence of induction, has been thrown into a state of tremor from mechanical violence. Such a true magnet parts with the greater portion of its magnetism by the gradual action of terrestrial induction.

Magnetic Needles.—A light bar or thin cylinder of magnetised steel adapted for suspension is called a magnetic needle. If poised on its centre of gravity and free to assume any position, its direction indicates the line of magnetic force of the earth at the place. But the forms of mounting with which we are here principally concerned are two, in which the needle is constrained to move in definite planes.

1. *The Horizontal-plane Needle* is one which is placed on a pivot, and so balanced by compensating weights that it moves only in azimuth. It is technically called *The Declination Needle*, and by seamen it is known as *The Variation Needle*. It indicates the angle which the magnetic meridian makes with the geographical meridian of the station. The declination is called east or west according as the marked end of the needle is drawn to the east or west of the meridian.

2. *The Vertical-plane Needle* is one hanging on a small horizontal axis and capable only of moving in altitude. It is technically called *The Inclination Needle*, but is more commonly known as *The Dipping Needle*. It indicates the angle which the line of magnetic force makes with the horizon. The inclination is called Positive or Negative according as the marked end of the needle inclines below or above the horizon.

Magnetic Needle, Astatic.—A magnetic needle withdrawn from the action of terrestrial magnetism, and therefore having *no statical* position of equilibrium with reference to the earth. It is of use to exhibit strikingly the effect of one magnet on another.

A single magnet may be rendered astatic by placing the axis on which it is movable in the direction of the magnetic dip; its motion will then be in the equatorial plane, and in this it will rest in any position.

The most convenient form, however, is a combination of two needles of equal power fixed in a frame one above the other, with opposite poles super-adjacent, and poised on a fine pivot. The united needles mutually neutralize the terrestrial magnetism on each, to which the whole together is thus rendered insensible. Each magnet however will be separately affected by the local attraction of another magnet brought near it, and each may be used as an "astatic needle".

Magnetic Needle, vibrating.—The relative magnitudes of the terrestrial magnetic horizontal force at different parts of the earth may be ascertained by observing the vibrations of the same magnet at these localities. Such a needle may also be used to find the relative magnitude of the horizontal component of a ship's magnetism. It is an essential instrument to the compass adjuster. The force is inversely as the square of the time occupied by each vibration; therefore the comparative intensities of the forces causing the vibrations are the ratio of the squares of the number of vibrations made in a given period of time.

A vibrating needle should be specially adapted for the purpose. It need be no more than three inches long, and it is convenient to prepare it so as to vibrate thirty times a minute when on shore and removed from the influence of all local disturbance. It may be suspended horizontally by a few fibres of silk. Those used in the Royal Navy vibrate on a special pivot which fits the vibrating box on shore and the compass bowl on board, and the pivot used on shore must be used on board.

Magnetic Needle; Axis, Neutral Line, Poles.

1. *Axis.*—The direction of the magnetic polarization of the needle. This should coincide with the longitudinal line of the needle itself, otherwise

the needle of the mariner's compass will not point with exactness to the magnetic north and south. At the Admiralty Compass Observatory the essential quality of coincident axes is made a point of special examination in all compasses, and the needles are placed with their edges on the card partly with a view to ensuring this result.—See **Compass, Imperfections, Adjustments, Errors.**

2. *Neutral Line.*—A line passing across the surface of the bar transversely to its length, and in which will be found the points where the magnetic force is zero. If the bar has been carefully magnetised this will be at its centre.

3. *Poles.*—The two points in which the attractive and repulsive power of the magnet appear to be concentrated. The distance of each pole from its end of the bar is about $\frac{1}{12}$ of the whole length. That pole of the compass needle which points to the earth's magnetic north is commonly called the "North Pole" of the needle for that reason, and the other the "South Pole". But these terms are objectionable as seeming to imply that like poles attract each other, which is the reverse of the truth. Hence it has been suggested to distinguish the pole of the bar which points to the North pole of the earth as the "Marked", and the other as the "Plain", end. Astronomer Royal Sir G. B. Airy adopts the convention of calling the magnetism of the earth's northern regions "Blue", and that of the southern "Red", and, as unlike poles attract each other, the end of a needle pointing to the north would be the "Red" end and the other the "Blue".

Magnetism, Terrestrial.—The magnetic influence of the earth, indicated by the difference and changes in magnetic phenomena observed on different parts of its surface. In treating of this force we must consider its *direction* and its *intensity;* and, in addition to these, the *distribution* of its effects over the surface of the globe, and what *changes* it is subject to. The distribution will be noticed under the heads of its direction and intensity, being represented in each separate case by a system of imaginary lines on the earth's surface; the changes will be noticed subsequently.

1. *The Direction of the Force of Terrestrial Magnetism* is estimated in two co-ordinate planes, the one horizontal the other vertical, in the former of which the geographical meridian is taken as the initial line, in the latter the horizontal plane is the origin. It is measured by the direction of magnetic needles suspended to move in each of these planes; the needle hung so as to move in the horizontal plane is called the "Declination" or "Variation needle", that hung so as to move in the vertical plane, the "Inclination" or "Dipping needle".

(i.) *The Direction in the Horizontal Plane.*—This is measured by the angle which the direction of the declination needle, (called the "magnetic meridian") makes with the geographical meridian. Imaginary lines on the earth's surface passing through all points where the needle points due north and south, are called *Lines of no Variation;* and lines passing through all points where the needle is deflected from the geographical meridian by an equal quantity, are called *Lines of Equal Variation*, or *Isogonic Lines.* These are extremely irregular curves, and form two closed systems surrounding two points which may be called the *Centres of Variation.* One of these points is in Eastern Siberia, the other in the Pacific Ocean in the vicinity of the Marquesas. The Isogonic Lines all converge to one point in the northern part of North America, Sir James Ross' Magnetic Pole: there is a similar convergence to a point in the Antarctic region to the southward of Australia and which is the South Magnetic Pole.

(ii.) *The Direction in the Vertical Plane.*—This is measured by the angle which the inclination needle makes with the horizon. At two points on the earth's surface, or rather in two small linear spaces, the needle assumes a position perpendicular to the horizon, one of its poles being downward in one hemisphere, and the opposite one in the other hemisphere. These two spots are called the *Magnetic Poles.* At the north magnetic pole, the "marked" or "red" pole of the needle dips; at the south magnetic pole, the "plain" or "blue" pole of the needle dips. The positions of these poles are lat. 70° N., long. 97° W., and lat. 73° S., long. 147° E. Encircling the earth is a line on every point of which the needle remains horizontal, or there is no dip; this line is called the *Magnetic Equator.* It crosses the terrestrial equator in several points, and never recedes from it on either side further than 16°; the position of the two being nearly coincident in that part of the Pacific where there are few islands, and most divergent when traversing the African and American continents. Intermediate to the poles and equator, lines are drawn through all points where the needle makes the same angle with the horizon. These are called *Lines of Equal Inclination* or *Dip*, or *Isoclinal Lines.*

2. *The Intensity of the Force of Terrestrial Magnetism* varies in different parts of the earth inversely as the square of the number of vibrations which the magnetic needle makes in a given time. There are four points on the earth's surface where the magnetic force is a maximum, two in each hemisphere, those of the greatest intensity lying in the southern hemisphere. These points are called the *Foci of Maximum Intensity.* The northern foci lie the one in Hudson's Bay, the other in Northern Siberia; the southern foci, one very near the other in the South Pacific, south of Tasmania; there is some doubt as to the existence of the second southern focus. An irregular curve, encircling the earth, is drawn through that point in each meridian on which the magnetic intensity is least; this is called the *Dynamic Equator.* The force is of unequal intensity in its several parts. This equator is considered by some magneticians the true line of separation between the northern and southern magnetic hemispheres. Again, intermediate to the foci and equator are lines passing through all the points where the magnetic intensity is the same; these are called *Lines of Equal Magnetic Intensity*, or *Isodynamic Lines.* In each hemisphere they first form a series of ovals round each of the foci there situated, having their major axis in the line joining the two foci. At a greater sweep a pair of these ovals join, and form a figure of ∞, and exterior to this single curves encompass both foci. These are first much inflected towards the point of junction, but become more regular as they approach the dynamic equator.

Terrestrial magnetism is influenced by causes which render its phenomena subject to *time-changes* affecting both its direction and intensity. The term "variations" is applied to all these, but we would prefer a word not already appropriated by common usage to a special use, and suggest "Fluctuations". There are *Secular Fluctuations* which take ages to run their course, and the causes of which are as yet unknown. Thus in London, previous to the year 1660, the needle is recorded to have had an eastwardly declination; subsequently it was found to have diverged to the westward, attaining its maximum of 24° 30′ W. about 1819, and then gradually returning towards the meridian again. At present it is about 18° W., and it is decreasing at about the rate of 8′ annually. Similarly the dip has been decreasing at London for the last fifty years at the rate of 3′ annually. We must here remark that our most recent observations tend to prove that the magnetic poles do not move, and of the motion of the foci of intensity we have no data to go upon. The great foci of magnetic *change* lie between North Cape of Norway and Cape Horn. There are also *Periodic Fluctuations*, which run through their course in ascertained periods, and which can be traced to their causes. Both the direction and intensity of terrestrial magnetism are influenced through the course of the year by the motion of the sun in the ecliptic, and they fluctuate with the declination of the moon and her distance from the earth. Again, there is the *Horary* or *Diurnal Fluctuation*, which, like the tides, goes through its changes twice in the twenty-four hours. Thus in the middle northern latitudes the N. pole of the declination needle has a mean motion from east to west from 8^h A.M. to $1\frac{1}{2}^h$ P.M.; it then returns to the east till evening, when it makes another excursion to the west, returning to its original position by eight o'clock in the morning. The angular extent of the excursion is greater in the day than in the night, in summer than in winter. In the middle latitude of Europe it is 13′ or 14′; on the equator, where it is very regular, 3′ or 4′. The phenomenon is reversed in southern latitudes. Once more, there are *Transient Perturbations* of terrestrial magnetism. Vast magnetic storms occur at irregular intervals, covering extensive areas of the globe. Earthquakes, electric changes, the aurora borealis, agitate the magnet, and disturbances synchronous with the appearance of solar spots have been observed.

Observations of terrestrial magnetism have for their object the determination of the above elements. Ships are supplied with instruments both for absolute and relative measurements, the latter being all that are possible at sea, while the former furnish base stations. Directions for the use of these instruments are given in a Paper by General Sir E. Sabine, in the Admiralty "Manual of Scientific Enquiry".* The results of such observations are embodied in charts and tables. [See article, "Terrestrial Magnetism" in "Elementary Manual for Deviations of Compass".]

Magnetism Charts.—There are three magnetism charts corresponding to the three classes of phenomena referred to above, viz. those exhibiting the *isogonic*, the *isoclinal* and *isodynamic* curves.† The epoch for which these charts are constructed, and to which all observations used should be reduced, ought to be definitely stated, as all the elements they embody change with the lapse of time.

(I.) *Chart of Lines of Equal Magnetic Variation.*—An inspection of this chart will give a good general view of the arrangement of the isogonic lines. The "Magnetic Meridian" of any place is given by the chart; the lines of no declination being the loci of places with no declination. These *agonic* lines cross the geographical equator at about 75° east and 48° west longitude. The surface of the globe is divided into two unequal regions by the agonic meridians, in the smaller of which, the Atlantic area, the variation is westerly; and in the larger, the Pacific area, the variation is easterly. The convergence to the two magnetic poles will be observed. This chart is most useful in the ordinary practice of navigation. When the total error of the compass has been found by astronomical observations, that part due to the declination or variation may be taken from the chart, leaving the remainder, which arises from the deviation of the compass. It thus furnishes, in these days of iron ships, a most needful means of checking, at any time and place, the Table of Deviations. This chart may also warn the navigator beforehand where the changes in the variation are most perplexing and dangerous, as where the lines are crowded together and lie athwart the usual tracks of ships, spots which happen to be the most frequented centres of maritime enterprise. So important is this chart, that one of them on Mercator's projection and on a large scale, embracing the whole navigable portion of the globe, and corrected to the epoch 1880, is supplied to each of H. M. ships.

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* Sold by John Murray, Publisher to the Admiralty. Price 3*s*. 6*d*.

† These three charts will be found in the "Admiralty Manual for the Deviation of the Compass", price 4*s*. 6*d*.; for the edition published this year (1882) entirely new charts have been constructed by Staff-Commander Ettrick W. Creak. They are also published in Keith Johnson's "Physical Atlas", and can be obtained in a detached form, with accompanying exposition.

(II.) *Chart of Lines of Equal Magnetic Dip.*—This chart shows that the arrangement of the isoclinal lines is somewhat analogous to that of the geographical equator and parallels of latitude. Hence the line of no dip is called the *Magnetic Equator*, and the isoclinal lines mark what is called the *Magnetic Latitude*, the *Magnetic Poles* being where the dip is 90°. It must however be borne in mind that the magnetic equator does not coincide with the geographical, and that the isoclinal lines are only generally parallel to the magnetic equator. The following relation is approximately true:

$$\text{Tan dip} = 2 \text{ tan mag. lat.}$$

The great use of this chart is the light it throws on the changes which the deviations of a ship's compasses undergo on a change of geographical position, chiefly those arising from induction; thus enabling a navigator to anticipate such changes. The magnetism induced in the soft iron by the vertical force of the earth is proportional to that force, and produces a deviation which varies, in different geographical positions, as the tangent of the dip. The value of this tangent is given, in the margin, for each isoclinal line on the chart. The deviation arising from the magnetism induced in the soft iron by the horizontal force of the earth is the same in all parts of the globe.

(III.) *Chart of Lines of Equal Horizontal Force.*—In some charts the curves of intensity are given showing the distribution of the *total* force, and the isodynamic curves, in these, will be arranged round four foci of maximum intensity, two in each hemisphere. At these centres the force is between two or three times the amount of that at the magnetic equator, where it is least. But the part of the force, as regards its intensity, which is of special importance to the navigator is the horizontal component; and it is this therefore, and not the total force, which is embodied in the Admiralty Chart. In studying this chart, it must be borne in mind that the relative positions of maxima and minima will be inverted from what they are when the total force is depicted. At the magnetic equator the vertical component vanishes, and so the horizontal component is identical with the whole of the total force; as we approach the magnetic poles, the vertical component increases while the horizontal component decreases, and the *relative* value of the latter becomes very small. Hence in intensity charts which exhibit the horizontal component only, the maximum will be found near the magnetic equator, and it will diminish as we go towards the poles; though the contrary of this is true when the total force is taken into account. This chart is most important in connection with the effects of the permanent magnetism of the hard iron of a ship. This is a disturbing cause which produces deviation inversely as the directive force of the needle (nearly). It is one of the parts of the semicircular deviation, and knowing its amount in a ship in any one part of the globe, this chart enables us to estimate its probable amount in any other locality. The multiplier for converting the permanent semicircular deviation at one place to that at another is the product of the value of the horizontal force at the first place, and of the reciprocal of the horizontal force at the second place. These reciprocals are given in the margin of the chart.

Magnetic Equator, Poles, Latitude.—These terms will be understood by a careful perusal of the articles on **Terrestrial Magnetism** and **Magnetism Charts**, but there are some ambiguities which cannot be too carefully guarded against. The terms, it must be borne in mind, have strictly reference to the magnetic dip.

1. The *Magnetic Equator* is the locus of the places where the dip is zero, or the aclinal curve to which isoclinals are approximately parallels. This curve is not identical with the line of minimum intensity of the total magnetic force which is called the *Dynamic Equator*, but is very approximate to the line of maximum intensity of the horizontal component. The magnetic equator again must not be confused with the *Equatorial Plane*, which is a plane, at any particular place perpendicular to the line of force, which line is indicated by the dipping needle, and may be regarded as the magnetic axis. This plane is perpendicular to the surface at every point of the magnetic equator, but its position varies in azimuth with the declination.

2. *The Magnetic Poles* are the places where the dip is 90° or the magnetic axis vertical. These are coincident with the spots where the horizontal component of intensity vanishes and where the equatorial plane is a tangent to the surface.

3. *The Magnetic Latitude* is generally defined as the distance of a place from the magnetic equator; but this is only approximately correct. All places on the same isoclinal line are, strictly speaking, in the same magnetic latitude, and these lines are only in a general sense parallel to the equator. Admitting the definition, and assuming the earth to be a sphere and the magnetic equator to be coincident with the dynamic equator, we may express approximately the different parts of the magnetic force in terms of the magnetic latitude, the horizontal force at the magnetic equator being taken as unit.

$$\text{Hor. force} = \text{cosin mag. lat.}; \ \text{vert. force} = 2 \sin \text{mag. lat.}$$

$$\text{Total force} = \sqrt{1 + 3 \sin^2 \text{mag. lat.}}$$

In point of fact the range of the total force is from 1 to about 2·3, and the foci of maximum intensity are not coincident with the magnetic poles.

Magnetic Meridian.—The direction of the declination needle at any place referred to the geographical meridian. Without great care a difficulty may result from the adoption of this term. The object of its use is simply to define that the direction of the horizontal component of the terrestrial magnetism at any place, indicated by the declination needle, is referred to the geographical north and south as the initial position. Obscurity is introduced by the initial lines of reference, converging to one point and the isogonic curves, which mark the changes of the magnetic meridian, converging to a different point. In the regions adjoining a magnetic pole, the magnetic meridian passes through every change of position; and as the initial lines or geographical meridians are nearly parallel for a small area, the variation passes through every value from 0° to 360°, reckoning, for simplicity, through the whole circle in the same direction. The same phenomenon is seen in the neighbourhood of a geographical pole resulting from the relatively opposite cause. Here the geographical meridian or initial line itself passes through every change of position; and if the declination needle be moved in a small circle round the geographical pole, it will remain parallel to itself for a small area, and hence the variation will here also assume every different value from 0° to 360°.

Magnetism of Ships.—See under **Compass Deviation.**

Magnitude of Stars.—The classes into which astronomers have distinguished the fixed stars, according to their apparent brightness. The brightest stars are said to be of the first magnitude, including about 23 or 24 principal stars; then come stars of the second magnitude, which exhibit a marked falling off in brightness from the first class, numbering about 50 or 60; stars of the third magnitude come next, comprising about 200; and so on down to the sixth or seventh, the numbers belonging to each increasing very rapidly as we descend in the scale of brightness. The seventh magnitude includes the smallest stars visible to the naked eye on the clearest and darkest night. The classes which follow, from the eighth to the sixteenth, form a separate division, being that of the telescopic stars. The difference of lustre between stars of two consecutive magnitudes is so considerable as to admit of intermediate gradations being acknowledged. At the first introduction of fractions into the nomenclature of brightness, a simple intermediate stage was recognized; thus a star intermediate in brightness to a star of the first and second magnitude, was described by a combination of the two figures, as 1.2 m; one between the second and third as 2.3 m; and so on. The interval was afterwards sometimes trisected, thus—1 m, 1.2 m, 2.1 m, 2 m; where 1.2 m represents a star whose magnitude is intermediate, but nearer the first than the second; 2.1 m a star whose magnitude is intermediate, but nearer the second than the first. This is the method adopted in the table of fixed stars in the "Nautical Almanac", pp. 290-293. More lately a decimal subdivision has been proposed in the place of the rougher forms of expression, but the nomenclature used in the "Nautical Almanac" is the more convenient one for the mariner to adopt. This classification is entirely arbitrary and conventional, and different observers differ in the magnitude they assign to the same star. Though loose and irregular, it serves for practical purposes, and must be accepted provisionally until astronomers have agreed upon some definite principle of photometrical arrangement.

Mantissa (L. "over-weight").—The decimal part of a logarithm. In the table of common logarithms, whose base is 10, the characteristics are omitted and the mantissæ only given.—See **Logarithms.**

Map (L. *mappa*, "a cloth"; hence Sp. *mapa*; It. *mappamonda*, the world spread out like a napkin).—A representation upon a plane of some portion of the surface of a sphere, on which are traced the particulars required, whether they be points or lines. A spherical surface, however, can by no contrivance be either "developed" or "projected" into a plane without undue enlargement or contraction of some of its parts. This is immaterial when only small portions of the sphere are to be delineated, but when large tracts are to be mapped down, the distortion in most cases is considerable and inconvenient. There are, however, different methods of projection, the defects of some being the reverse of those of others, and some systems are specially adapted for certain purposes. The word map is a general term, but it has also a more limited sense. Regarding the earth's surface, the word "map" is commonly confined to delineations in which the *land* is the principal subject of consideration—the map of the geographer; and it is then distinguished from a "chart", in which the *water* is the principal subject of consideration—the map of the hydrographer. [See **Chart.**] The term map includes delineations of the celestial sphere.

Mariner's Compass.—A compass fitted for use on board ship. According to the purposes for which it is specially adapted, it is named *the Steering Compass, the Azimuth Compass, the Standard Compass.*—See under **Compass.**

Markab.—The name of the bright star *a Pegasi.*—See **Pegasus.**

Marks.—The depths of the lead-line, which are "marked" by having a distinguishing piece of leather, cord, or bunting rove through the strands. They are, the 10 fathoms (leather with a round hole), 20 fathoms (piece of cord with two knots), and three intermediate to each of these—the 3 fathom (leather), 5 (white rag), 7 (red rag); the 13 (blue rag), 15 (white rag), 17 (red rag). The *marks* are distinguished from the *deeps.* When the lead gives one of these soundings the "leadsman" sings it out as, "*By the mark* ——".—See **Lead-line.**

Mars (named after the Roman god of war).—The superior planet coming next in position to the earth, and being fourth in the order of distance from the sun. Its actual diameter is a little more than one-half that of our globe. The apparent angular diameter of **Mars** varies from 4″

to 18″, and it can be distinguished by its red and fiery appearance. It is one of the "lunar-distance" bodies. Symbol ♂.

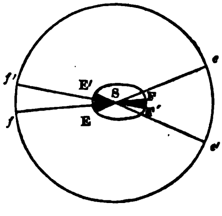
Masthead Angler.—See under **Angle.**

Maxima and Minima. (L. "the greatest and the least").—The maxima values of a varying quantity are those which it has at the moment when it ceases to increase and begins to decrease; the minima values those which it has at the moment when it ceases to decrease and begins to increase. The terms do not refer to the absolute greatest or least value of which the quantity is susceptible. Example: When the barometer rises and then falls, its height at the change is a maximum, even though it should subsequently attain a greater height; when, after falling, it commences to rise, the height at the change is a minimum, even though it should subsequently fall to a greater extent.

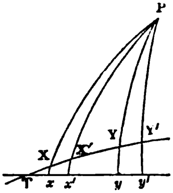
Maximum (L. "the greatest").—A value which a varying quantity has at the moment when it ceases to increase and begins to decrease.—See **Maxima and Minima.**

Mean Level of the Sea.—The middle plane between the levels of high and low water.—See **Level of the Sea.**

Mean Sun.—A fictitious sun which is conceived to move uniformly in the equinoctial with the mean velocity the real sun has in the ecliptic. The mean sun furnishes us with a uniform measure of time, and the need for the conception arises from apparent solar time being variable. The apparent solar day is variable from two causes—(1) the variable motion of the sun in the ecliptic, and (2) the ecliptic not being perpendicular to the axis of the earth's rotation. (1) The earth moves in an elliptic orbit (EE′FF′) round the sun in one of the foci (S), and, by a



law of such motion, sweeps out equal areas (as ESE′ and FSF′), and therefore describes unequal angles as (ESE′ and FSF′) in equal times. Hence the sun appears to move sometimes faster and sometimes slower in the ecliptic (describing, for example, *ee′* and *ff′* unequal arcs in equal times). He, in fact, at one time describes an arc of 57′ in a day, and at another time as much as 61′. This will cause the apparent solar day to vary in length. (2) But, again, even supposing the motion of the sun in the ecliptic to be uniform, this circle is not perpendicular to the axis of the earth's rotation, and, consequently, equal arcs will not subtend equal angles at the pole of the heavens, such angles measuring equal intervals of time. Let XX′ and YY′ be equal arcs of the ecliptic, the former near the equinoctial point (♈), where the ecliptic is inclined to the equinoctial at an angle of about 23° 28′, and the latter in the vicinity of the solstitial point, where the two circles are parallel. Draw the hour-circles PX*x* PX′*x′* and PY*y* PY′*y′*; then it is evident that the angles at the pole *x*P*x′* and *y*P*y′*, or the corresponding arc of the equinoctial, are *not* equal.

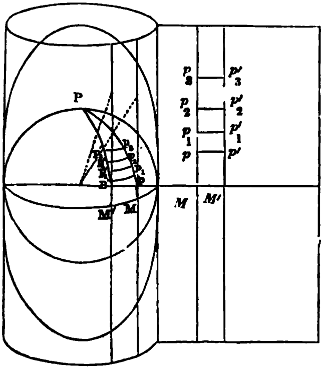


The connection between the true and mean sun is established as follows: Imagine a star to move along the ecliptic with the mean or average motion of the true sun, the two starting together from the extremity of the major axis of the ellipse. Let our fictitious sun so move in its uniform course along the equinoctial that it and the star may cross the first point of Aries together, at which time the true sun will be a little ahead. The true and the mean sun will never be together, but four times a year they will be in the same declination circle; the equation of time, which is the difference between the right ascensions of the two suns, will therefore vanish four times a year.

Mean Time.—Time in which the unit of duration is a mean solar day, the length of which is the average of the days throughout the year.

Its lapse is astronomically defined by the motion of the fictitious point called the mean sun; for practical purposes it is measured by machinery. —See **Time.**

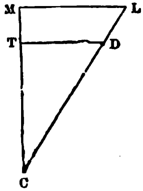
Mercator's Chart.—A chart constructed on what is called Mercator's projection. All the meridians are parallel right lines, and the degrees of longitude are all equal; the parallels of latitude are at right angles to the meridians, and the degrees of latitude increase in length from the equator to the pole in the same proportion as the degrees of longitude decrease on the globe. It may be constructed with the aid of a Table of Meridional Parts. The property which makes the Mercator's chart so useful for purposes of navigation is, that on it alone the track of a ship always steering the same course appears as a straight line.



Mercator's Projection of the Sphere.—A method of delineating the surface of a sphere on a plane, named after its partial inventor Gerard Kauffman, the Latin equivalent of whose name is *Mercator* ("merchant"). He was born in East Flanders in 1512. The method is called a "projection", but to prevent misconception, we must bear in mind that it is not a projection according to the strict meaning of the word. To mark this, and distinguish it from *natural* perspective representations, it is classed as an *artificial* projection. The principle of projection, however, may, as far as it applies, be used to explain this method of delineating the terrestrial surface. The meridians are obtained by referring every point on the globe to a circumscribing cylinder which touches the globe along the equator, the eye being situated in the centre. This cylinder is then unrolled or "developed" into the "primitive" plane. On this plane the meridians will therefore appear as equidistant parallel straight lines at right angles to the equator. The rest of the delineation is made without any reference to projecting visual rays emanating from a *fixed eye*, but the result (as far as *form* is concerned) is such as would appear to an eye carried successively over every part of the surface of the sphere. The parallels of latitude are drawn parallel to the equator, and at such increasing distances from each other, that degrees of longitude and degrees of latitude bear always their due proportion. Let pp', $\mathrm{p}_1\mathrm{p}_1'$, $\mathrm{p}_2\mathrm{p}_2'$, $\mathrm{p}_3\mathrm{p}_3'$, etc., be arcs of equidistant parallels of latitude intercepted between two meridians PM, PM', and therefore decreasing in length as they recede from the equator; the figures $\mathrm{pp}'\mathrm{p}_1'\mathrm{p}_1$, $\mathrm{p}_1\mathrm{p}_1'\mathrm{p}_2'\mathrm{p}_2$, $\mathrm{p}_2\mathrm{p}_2'\mathrm{p}_3'\mathrm{p}_3$, etc., are supposed to be indefinitely small. On the projection, the corresponding arcs of the parallels pp', p_1p_1', p_2p_2', p_3p_3', etc., are all equal to MM', and therefore they have been unduly lengthened, and more and more so as they recede from the equator; hence the increments of the meridian (*i.e.* the small portions successively added to the length under consideration), which are equal on the globe (pp_1, $\mathrm{p}_1\mathrm{p}_2$, $\mathrm{p}_2\mathrm{p}_3$, $\mathrm{p}_3\mathrm{p}_4$, etc.), must be magnified in the projection (pp_1, p_1p_2, p_2p_3, p_3p_4, etc.), and more and more so as they recede from the equator. If they are made to lengthen in the same proportion as the arcs of the parallels of latitude ($\mathrm{p}_1\mathrm{p}_1'$, $\mathrm{p}_2\mathrm{p}_2'$, $\mathrm{p}_3\mathrm{p}_3'$, etc.) were lengthened in the projection (p_1p_1', p_2p_2', p_3p_3', etc.), then the small areas of the projection, $pp'p_1'p_1$, $p_1p_1'p_2'p_2$, $p_2p_2'p_3'p_3$, etc., will be depicted similar to the corresponding arcs of the sphere $\mathrm{pp}'\mathrm{p}_1'\mathrm{p}_1$, $\mathrm{p}_1\mathrm{p}_1'\mathrm{p}_2'\mathrm{p}_2$, $\mathrm{p}_2\mathrm{p}_2'\mathrm{p}_3'\mathrm{p}_3$, etc., and the representation is a Mercator's projection. It is evidently a true representation as to *form* of every particular small tract, but varies greatly in point of *scale* in its different regions, each portion being more and more extravagantly enlarged as it lies farther from the equator. The construction of the Mercator's chart may perhaps be more clearly explained by the idea of *development* than by that of *projection*. Conceive a hollow globe of elastic material with the various lines of the terrestrial sphere, and the map of the world printed upon it, the ink remaining wet, and so capable of being transferred to any other surface, and let this globe be touched along the equator by a circumscribing cylinder. Now, imagine the globe to be inflated so that it expands and fills up the cylinder, the expansion ceasing at each point as soon as that point comes into contact with the cylinder, and the elasticity of the material being such as to expand equally in all directions. As such portion of the globe comes thus in contact with the interior surface of the cylinder, the meridians and parallels with the map of the countries will be impressed upon the latter, and being finally unrolled it will exhibit a Mercator's chart.

The characteristic feature of the Mercator's projection may be briefly stated thus—*The increments of the meridian* (or the small portions by which it is successively increased) *vary as the secants of the latitude.* [See **Meridional Parts.**] Though Mercator made his degrees of latitude increase with their distance from the equator, he was ignorant of this law which regulates them. It was discovered by Edward Wright, an Englishman, who made it public in 1594. It will be seen at once, from the manner in which the meridians are projected, that a spiral on the globe which cuts them at a constant angle (the rhumb) will be projected on the plane into a straight line. It is this property which renders the Mercator projection so invaluable to the navigator.

Mercator Sailing.—A method which completely solves the problems of spherical sailing, and which is characterized by the use of the *Table of Meridional Parts*, and the chart constructed by means of it called *Mercator's Chart.* With the assistance of this table, the rules of plane trigonometry suffice for the solution of all the problems. In the triangle CTD, let C be the course, CD the distance, CT the true difference of latitude, TD the departure; then, corresponding to CT, the Table of Meridional Parts gives CM the meridional difference of latitude, and,



completing the right-angled triangle CML, ML will be the difference of longitude. In addition, then, to the three canons of *plane sailing* which can be deduced from the triangle CTD, the triangle CML gives the characteristic canon of *Mercator sailing* (since $ML = CM \,.\, \tan C$).

Diff. long. = mer. diff. lat. × tan course.

Mercury (called after the Roman god of merchandise).—One of the inferior planets—that which revolves nearest to the sun, from which it never attains a greater angular distance than about 29°. It is seldom visible to the naked eye and then only at sunrise or sunset. Its actual diameter is about two-fifths that of the earth; the apparent angular diameter varies from 5″ to 12″. Symbol ☿.

Meridians (L. *meridies*, from *medius dies*, "mid-day").—If we consider the earth a sphere, the meridians are great circles of the earth passing through the poles. They are so called because they mark all places which have noon at the same instant. They are secondaries to the equator, and on them latitudes are reckoned north and south from that primitive. They mark out all places which have the same longitude, and are hence called "*Circles of Longitude*". It is usual to consider each *semicircle* joining the two poles of the earth as a meridian. The above definition is only correct if the earth is regarded as a sphere. If we take into account that the earth is an oblate spheroid, it must be replaced by the following: Meridians are curves which are the sections of the earth's surface by planes passing through the two poles. These curves are ellipses whose major and minor axes are respectively the equatorial and polar diameters of the earth.

Meridian (Terrestrial) of an Observer.—The section of the earth by a plane passing through the poles and the station of the observer. If the earth is regarded as a sphere, this section is a great circle; if its spheroidal figure is taken into account, the section is an ellipse.

Meridian (Celestial) of an Observer.—The great circle of the celestial concave in which the plane of the terrestrial meridian indefinitely extended intersects it. It is the circle passing through the elevated pole of the heavens and the zenith of the observer. By the rotation of the earth the observer's meridian, like the horizon, sweeps daily from west to east across the heavenly bodies projected on the celestial concave. If the earth be conceived to be at rest, the meridian is a fixed circle, and all the heavenly bodies are carried across it in their diurnal courses from east to west. It thus, as its name expresses, serves as a circle of reference for the diurnal motions of the heavenly bodies; great circles of the heavens co-axial with it, and passing through these several bodies, are called their "hour-circles". We must carefully bear in mind the distinction in the phrases—"the celestial *meridian* of an *observer* on the earth", "the *hour-circle* of a *heavenly body*". With reference, however, to the diurnal motion, the meridian is considered the initial position of the hour-circles, which thus mark out at the pole "hour-angles", reckoning westward. The celestial meridian intersects the horizon in the north and south points, and its poles are the east and west points. The celestial meridian is often simply spoken of as "*The Meridian*".

Meridian Line.—A meridian line is the line in which the plane of the meridian of any station intersects the plane of the sensible horizon; it meets the celestial horizon in the north and south points.

Meridian Altitude.—The meridian altitude of a heavenly body is its altitude when on the meridian of the observer's station. It is the *greatest* altitude which the body attains in its diurnal revolution, or, when the body culminates twice, the greatest and the least altitude. The meridian altitude is easily observed at sea with the sextant, when the body comes to the meridian its image appearing to remain stationary for a short time and then to "dip".

Meridian Distance.—The difference in time between the meridians of two places. This is an application of the term "distance" which is confusing and unnecessary. We recommend the substitution of *Chronometric Difference* as being much more appropriate.—See **Longitude; Difference of, in Time.**

Meridian Zenith Distance.—The meridian zenith distance of a heavenly body is its zenith distance when on the meridian of the observer's station. It is the complement of the meridian altitude.

Meridional Difference of Latitude.—The quantity which bears the same ratio to the difference of latitude that the difference of longitude bears to the departure. It is the projection of the difference of latitude on the Mercator's chart, and takes its name from the "Meridional Parts", by the use of a table of which it is found. In contradistinction to it, the difference of latitude of plane sailing is in spherical sailing qualified as the *True Difference of Latitude.*

Meridional Parts.—At the equator a degree of longitude is equal to a degree of latitude, but, as we approach the poles, while (supposing the earth to be a perfect sphere) the degrees of latitude remain the same, the degrees of longitude become less and less. In the chart on Mercator's projection the degrees of longitude are made everywhere of the same length, and therefore, to preserve the proportion that exists at different parts of the earth's surface between the degrees of latitude and the degrees of longitude, the former must be increased from their natural lengths more and more as we recede from the equator. The lengths of small portions of the meridian thus increased, expressed in minutes of the equator, are called "meridional parts"; and the *Meridional Parts for any latitude* is the line, expressed in minutes (of the equator), into which the latitude is thus expanded. The meridional parts computed for every minute of latitude from 0° to 90°, form the *Table of Meridional Parts,* which is chiefly used for finding the meridional difference of latitude in solving problems in Mercator's sailing, and for constructing charts on the

Mercator projection. The value of the meridional parts may be obtained approximately from the formula—

$$\text{Mer. parts for } l^\circ = \sec 0 + \sec.\ 1' + \sec 2' + \ldots . + \sec (l^\circ - 1');$$

and it was from a similar expression that the first table of meridional parts was computed by Edward Wright in 1594. The integral calculus now furnishes the means of finding the meridional parts correctly, the formula obtained being—

$$\text{Mer. parts for } l^\circ = \frac{180 \times 60}{\pi} \log_e.\ \tan\left(45^\circ + \frac{l^\circ}{2}\right).$$

Meridional Projection of the Sphere.—A projection of the sphere, whether orthographic, stereographic, or central, in which the primitive or plane of projection coincides with or is parallel to the *meridian.*

Meteorology (Gk. τὰ μετέωρα, "things in the air"; λόγος, "a treatise"). —The science which treats of the atmosphere and its phenomena; for the navigator it is the science of the winds and the weather. The various subjects of which it takes cognisance will be indicated by the mention of some of the principal instruments used. The *Barometer* (Gr. βάρος, "weight") measures the pressure; the *Thermometer* (Gk. τὸ θερμὸν, "heat"), the temperature; and the *Hygrometer* (Gk. τὸ ὑγρὸν, "moisture"), the moisture of the atmosphere; the *Anemometer* (Gk. ἄνεμος, "wind") indicates the strength and velocity of the wind; and the *Pluviameter* (L. *pluvia*, "rain") gauges the rain.

Mètre (Fr., from Gk. μέτρον, "a measure").—The French standard measure of length, being the ten-millionth part of the quadrant of the meridian. The other measures of length are referred to this, the whole system being decimal; Latin prefixes are used to indicate division, Greek prefixes multiplication. Thus a *decimètre* (*decem*, "ten"), is the tenth of a mètre; a *centimètre* (*centum*, "a hundred"), the hundredth part of a mètre; a *millimètre* (*mille*, "a thousand"), the thousandth part of a mètre. Again, a *decamètre* (δέκα, "ten") is ten mètres; a *hectomètre* (ἑκατὸν, "a hundred") is one hundred mètres; a kilomètre (χίλιοι, "a thousand"), one thousand mètres; a *myriamètre* (μυριὰς, "ten thousand"), ten thousand mètres. A mètre is equal to 39·37079 English inches; and from this all the other French measures may be obtained by shifting the decimal point.

Middle Latitude.—With reference to two places situated in the same hemisphere, the middle latitude is the latitude of the parallel passing midway between them; its value is therefore half the sum of the latitudes of the two places. When the places are situated in different hemispheres, the simple "middle latitude" is replaced by the two "half latitudes" of each of the places.

Middle-Latitude Sailing.—An approximate method of solving certain cases of spherical sailing, founded on the consideration that the arc of the parallel of middle latitude of two places intercepted between their meridians is nearly equal to the departure. If the ship is conceived to sail along this middle parallel, we may apply the principle of *parallel sailing* to the cases in point. In parallel sailing the departure (or distance) and difference of longitude are connected by the relation,—

$$\text{Dep.} = \text{diff. long.} \times \cos \text{lat.}$$

When the ship's course lies obliquely across the meridian, making good a difference of latitude, a modification of this formula gives the formula for middle-latitude sailing,—

$$\text{Dep. (nearly)} = \text{diff. long.} \times \cos \text{mid. lat.};$$

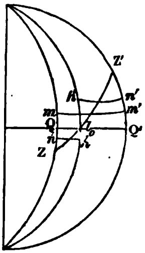
or, in logarithms,

$$\text{log. dep.} = \text{log. diff. long.} + \text{L} \cos \text{mid. lat.} - 10.$$

In the proof of the fundamental principle of middle-latitude sailing two cases must be considered separately—(1) When the place from and the place in are on the same side of the equator, and (2) When they are on different sides of it.

1. Let the two places Z and Z′ [figure, **Rhumb Sailing**] be in the same hemisphere, Z being nearer to the equator than Z′. Draw the middle parallel *mzm′* intersecting the rhumb line Z*z*Z′ in *z*. Then the segments of the portion of the parallel *mz*, intercepted between successive meridians between those of Z and *z*, are respectively less than the arcs of departure d_1r_1, d_2r_2, ... on the side adjacent to the equator; and the segments of the portion of the parallel *zm′*, intercepted between successive meridians between those of *z* and Z′ are respectively greater than the arcs of departure d_9d_9, d_8d_8, ... on the side remote from the equator. The excess on the one side cannot be very different from the defect on the other. Hence *mm′* may be taken as an approximation for the departure, especially for short distances; and as far as the departure is concerned, and consequently the difference of longitude, the ship may be supposed to have sailed along the parallel *mm′*. Thus the case is reduced to parallel sailing.

2. When the two places Z and Z′ are in different hemispheres, their latitudes being of different names, the middle latitude fails to give an arc of a parallel which is an approximation to the departure. Practically, however, when the latitudes are of contrary names, no sensible error can arise from taking the departure itself made good from day to day as the difference of longitude. For greater distances we may consider separately the departure made good on each side of the equator, and thence find the difference of longitude, though the plan fails for the converse problem. Thus, let the rhumb line between Z and Z′ cut the equator in l_o, and let *nh* be the arc of the parallel of the half latitude of Z intercepted between the meridians of Z and l_o, and *n′h′* the arc of the parallel of the half latitude of Z′ intercepted between the meridians of Z′ and l_o. Then by previous case,



nh is an approximation to the departure in sailing from Z to l_o
and *h′n′* do. do. l_o to Z′
∴ *nh* + *h′n′* do. do. Z to Z′

Hence it will be seen that we can thus deduce the difference of longitude $Ql_0 + l_0Q'$; but conversely we cannot find the approximate departure $nh + h'n'$ from the difference of longitude QQ′, since the position of the point l_0 is not known. For ordinary purposes, when the two latitudes are numerically very nearly equal, or very unequal, correct enough results will be obtained by employing as the middle latitude half the greater latitude. In intermediate cases we may combine the two middle latitudes, giving the greater weight to that which corresponds to the greater latitude. The fundamental problems of navigation may be completely (though only approximately) solved by the middle-latitude method, just as they are in parallel sailing by inspection of the traverse tables.—See **Sailings.**

Mile (L. *miliare*, the *mille passus* "thousand paces" of the Romans).—The Roman pace was 5 Roman feet, each equal to about 11·62 English inches. The ancient Roman mile was, therefore, equal to 4842 English feet, or 1614 yards.

Mile, English Statute.—The common and authorized mile used by the English for itinerary and legal purposes. It consists of about 1090 ancient Roman paces. Its length is incidentally laid down, in a Statute (forbidding persons to build within three "miles" of London) of the 35th year of Queen Elizabeth, as being 8 furlongs (a contraction for forty-"longs") of 40 perches of 16½ feet each. This is more easily remembered as being 8 furlongs of 220 yards each; and it is equal to 80 land-surveying chains of 22 yards each.

1 statute mile = 1760 yards = 5280 feet.
1 English statute mile = 1·61 French kilomètre.

Mile, Geographical or Nautical.—The *Geographical Mile* was formerly defined as "the length of a minute of the earth's circumference"; and it is hence also called a "*Minute*". It is that used in navigation, and hence called the *Nautical Mile*, and also a "knot", from the manner by which the rate of a ship is obtained and estimated in it.

The above definition of the mile used at sea, "the length of a minute of the earth's circumference", is very inadequate; but it is purposely here given as a general and preliminary one to explain the different values assigned to the nautical mile in books on navigation, which are very perplexing to the mariner. It was sufficient before the spheroidal figure of the earth was taken into account, and when the assumption was that the earth's circumference was a great circle, the measurement of which had not been accurately determined.

Sir Jonas Moore [" A New Systeme of the Mathematicks", 1681] takes the length of "a minute of a degree of a great circle of this terraqueous globe" to be 6000 English feet. The general custom before his time was to use the value 5000 feet, but experience had proved that the distance run, obtained by a corresponding "knot", "did not answer to the parts of a degree", and the half-minute glass had been shortened in consequence by about 5 seconds of time. *John Robertson* ["The Elements of Navigation", 1786] deduces the length of a "sea" or "nautical mile" to be 6120 feet, as "by Mr. Richard Norwood's experiment it appears that a degree of a great circle on the earth contains 367,200 English feet". *John Riddle* calculates the nautical mile to be nearly 6079 feet, on the assumption that the earth is "nearly equal to a sphere of 7916 English miles in diameter."

The section of the earth which approaches nearest to a great circle is the equator, though the greatest and least diameters of even the equator differ by about 9768 feet. Taking Bessel's value of the equatorial diameter of the earth, viz. 41,847,192 feet, the length of a minute of this great circle would be 6086 feet, which nearly corresponds to the length of the nautical mile (viz. 6086·7) used by *Nathaniel Bowditch* for finding the length of the knot [see "The New American Practical Navigator"]. Besides the objection to this value as not giving a knot sufficiently accurate for the greater part of the seas, there is the further objection to the principle by which it is obtained, viz. that the length of the mile is connected with a minute of a degree of longitude.

The nautical mile should always be associated with the length of a minute of a degree of latitude. The meridian, however, being an ellipse, this varies much in different latitudes, at each spot depending upon the radius of curvature. At the equator the length of the minute of latitude is 6045·93 feet; in latitude 45° it is 6076·82 feet; at the pole it is 6107·98 feet. If we define the nautical mile as "the mean length of a minute of latitude", its value would thus be about 6077 feet. *James Inman* uses 6075·5 as the value of "a mean nautical mile". *Henry Raper*, for the purpose of computing a Table of Depression, finds "the length of the average nautical mile 6082 feet (nearly)." To obtain this "average length" he assumes an arbitrary latitude, viz. 40°, marking the region most frequented by shipping; and, as the curvature of the earth is different on the prime vertical and on the meridian, he employs the circle of curvature crossing the meridian at 45° of azimuth. In estimating, however, the length of the "knot", he uses the approximate value 6080 feet. *H. W. Jeans* follows this practice. The number 6080 has been generally adopted as a convenient value for the knot, and is in general sufficiently near for practical purposes. It is strictly the value of a minute of latitude on the parallel of 48°.

The nautical mile in use is, in fact, different according to the purpose for which it is employed. There are three distinct applications of it in cognate branches of naval science, which should not be confused, and for which it is desirable we should have separate definitions.

1. The **Hydrographer's Mile** is "the length of a minute of latitude on the parallel under treatment".

2. The **Navigator's Mile** is "the average length of a minute of the meridian".

3. The **Ship-builder's Mile** is "the measured mile of a fixed number of feet".

1. *Hydrographers* use every different value of the geographical mile, and construct their local charts on the basis that the mile is a mile of latitude on the parallel under treatment. But, as a mile should be

understood as a fixed quantity, there is an anomaly in so using the term unless there is associated with it a definite measure, such as a mile of 6080, or 6085, or 6086 feet, as the case may be. Our surveyors, therefore, invariably make a notation of this value, which is obtained from Geodetical Tables.

2. *Navigators* use a mean value of the geographical mile. This, as we have seen, has varied at different periods with advancing knowledge of the earth's form and magnitude. It is that which is technically termed the "knot", and is used to estimate the ship's run at sea. In navigating a ship in equatorial and polar regions we should, if rigidly accurate, have to change the length of the knot with the latitude; but for the ordinary purposes of navigation the average nautical mile may be used in high and low latitudes without fear of error as affecting the ship's run. The mean value of a mile of latitude, viz. that on the parallel of 45°, is 6077 feet; there seems to be no reason why this value should not be universally adopted, except that the number 6080 commonly used is easily remembered, and the difference resulting from the use of the two would not amount to one mile in 2000.

3. *Ship-builders*, since the introduction of steamers, have adopted a nautical mile of fixed value in feet to test a ship's speed. This is called a "measured mile." A uniform measured mile has not, however, been defined by authority. The Admiralty itself uses two different lengths, the measured mile on the Thames being 6085 and that at Plymouth being 6083 feet. This difference, as given on the charts, may possibly be accidental, or perhaps it is a remnant of the times when rival constructors at Woolwich and Devonport were independent and adopted a value for their measured mile from the approximate geographical mile of the latitude of their dockyard. Should a uniform "measured mile" ever be introduced, it would be desirable to assimilate [illegible] ich is afterwards used in logging the rate of a ship at s

Miles, Geographical and Statute.—The lengt phical mile being 6076·82 and that of the English statute mile being 5280 feet; we have—

1 Geographical mile = 1·151 statute mile,
1 Statute mile = ·868 geographical mile.

The convergent fractions which express the ratio of the geographical mile to the statute mile are—$\frac{1}{1}$, $\frac{7}{6}$, $\frac{8}{7}$, $\frac{75}{73}$, $\frac{23}{20}$, $\frac{61}{53}$, $\frac{433}{376}$, etc.

Mile, Metrical.—The French "kilomètre" (1000 mètres) is sometimes so called. It is the length of one-hundredth part of a quadrant of the meridian. A kilomètre = 39370·79 English inches = 3281 feet = 1093 yards = ·62 statute mile. This mile is the same as the *Mijle* of the Netherlands and the *Stadion* of Greece.—See **Mètre.**

Milky Way (L. *Via Lactea*; Gk. *ὁ γαλαξίας κύκλος* "The Galaxy").—A luminous zone (varying in breadth from 5° to 22°) visible on a clear night, and which may be referred to a great circle of the sphere named by Sir John Herschel *The Galactic Circle.* This circle is inclined at an angle of about 63° to the equinoctial, which it cuts at points whose right ascensions are $0^h\ 47^m$ and $12^h\ 47^m$. The phenomenon is the result of the light of innumerable stars of every magnitude, from such as are visible to the naked eye down to the smallest point of light perceptible with the best telescope. The appearance of these as a belt is explained by the hypothesis of Sir William Herschel that the grouping of the stars of our firmament is in the form of a stratum, of which the thickness is small in comparison with its length and breadth, and that the solar system is situated somewhere about the middle of its thickness. A visual ray traversing from the edge of such a lamina would pass through more stars than one perpendicular to the lamina.

The principal use of the Milky Way to the seaman is the aid it affords him in recognizing the stars, especially on a bright night, when it is more difficult than usual to single out the body required for an observation. The most convenient way to study it, in each hemisphere, is to take for our starting point the spot where it approaches nearest the pole; and it so happens that in both cases this is marked by a conspicuous easily detected constellation.

Northern Hemisphere.—CASSIOPEIA'S CHAIR is situated near the spot where the Galaxy passes closest to the North Pole. From this point, if we follow it in the direction of the diurnal motion of the heavens, it passes through *Cepheus*, sending off a spur towards the Pole; in *Cygnus* it divides, unites again and then separates into two branches. The branch nearest to the Pole, after passing to the south of Lyra, terminates near α and β *Ophiuchi*. The other branch passes through *Aquila*, then widens out till it comes to *Sagittarius* and at γ Sagittarii it suddenly collects into a vivid oval about 6° in length and 4° in breadth, the product of upwards of 100,000 stars. A parallel patch here appears in Scorpio. If we now return to CASSIOPEIA and advance in a direction contrary to the diurnal motion of the heavens, the Way passes through *Perseus*, where it sends off an offshoot to a considerable distance; then it passes near *Auriga*, between *Taurus* and *Gemini*, and between *Orion* and *Canis Minor;* after bending round *Sirius* and sending off a branch near μ *Puppis*, in *Argo* it opens out into a wide fan-like expanse nearly 20° in breadth which terminates abruptly and a wide gap succeeds.

Southern Hemisphere.—The SOUTHERN CROSS is situated near the spot where the Galaxy passes closest to the South Pole. Here also is one of its most remarkable black patches, caused by an entire absence of stars. This space is of an irregular pear-shaped form about 8° in length and 5° in breadth; such a striking object is it that the early navigators called it the *Coal Sack*. From this point, if we follow the Way in the direction of the Diurnal motion of the heavens we soon come to *Argo*, to which locality we have traced it from CASSIOPEIA. If we proceed from the *Coal Sack* in a direction contrary to the diurnal motion, the Way passes *Centaurus*, then widens out and subdivides into several irregular branches and patches which permeate *Scorpio*. To this locality we have also traced it from CASSIOPEIA.

Millimètre (L. *mille*, "a thousand"; Fr. *mètre*).—A French measure of length, being the thousandth part of the mètre, and equal to ·039 English inch.

Minimum (L. "the least").—A value which a varying quantity has at the moment when it ceases to decrease and begins to increase.—See **Maxima and Minima.**

Minute.—A nautical mile is sometimes so called as being the mean length of a minute of latitude. A minute of latitude is often conversely called "a mile", which, however, is not quite correct, as, while the mile is of invariable length, the minute of latitude varies on different parts of the meridian. Great care should be taken not to call a minute of longitude "a mile", as the minute of longitude is of very different lengths in different latitudes.

Monsoons (Arabic and Malay, *mosseem*, "a year").—A term originally used for the periodic winds of the Indian Ocean, but now extended to include all currents of the atmosphere caused in a similar manner. They are for the most part trade-winds deflected at stated seasons of the year, and are found in regions where the sun in one part of his course is vertical to large tracts of arid land, and at another part of his course over large tracts of sea. Thus the African monsoons of the Atlantic, the monsoons of the Gulf of Mexico, and the Mexican monsoons of the Pacific, are formed of the trade-winds which are turned or deflected to restore the equilibrium which the overheated plains of Africa, Utah, Texas, and New Mexico have disturbed: and similarly in the Indian Ocean, where the monsoon phenomena are developed on the grandest scale, their range being the whole expanse of northern water that lies between Africa and the Philippine Islands. The heat of summer creates a disturbance in the atmosphere over the interior plains of Asia, which is more than sufficient to neutralize the forces which would cause a regular north-east trade-wind. The north-east trade-wind is arrested and turned back, and the result is a south-west monsoon, which continues for six months from April to October. During the other six months, from October to April, these causes act in concert with the trade-wind, and what in other seas would be called the north-east trade, is in this case called the north-east monsoon. The south-west monsoons commence at the north, and " back down ", or work their way towards the south; thus they set in six or eight weeks earlier at the tropic of Cancer than at the equator. The change from the one to the other is accompanied by violent rains, with storms of thunder and lightning. It is this south-west boisterous wind that is generally spoken of as **The Monsoon.**

Moon (Sax. *mona:* analogues—Lat. *luna;* Gk. σελήνη, both which words are sometimes found in derivatives, *e.g. lunation, selenography*).— The secondary planet or satellite of the earth, revolving in an orbit round the earth, being at the same time carried with it, and participating in its motion round the sun; the actual orbit, therefore, which the moon describes in space is very complicated. The moon's distance from the earth is about 60 times the earth's radius, and her actual diameter 2153 miles. But it is with the apparent orbit of the moon and resulting phenomena, her apparent size, the effect of her proximity to an observer, and with her influence, that the practical navigator is chiefly concerned.

The *apparent orbit* is, speaking generally, a great circle of the heavens, like that which the sun appears to describe round the earth. In this circle the moon seems to advance rapidly among the stars with a movement contrary to the diurnal revolution of the heavens. Progressing sometimes quicker, sometimes slower, she completes the tour of the heavens in an average period of $27^d\ 7^h\ 43^m\ 11{\cdot}5^s$. This motion among the stars is the foundation of several important methods for determining the longitude, " lunar distances ", " occultations ", and " moon-culminating stars ".

The *apparent diameter* of the moon varies with her distance from the earth, the greatest value being 33′ 31′, and the least 29′ 22″. The semi-diameter is one of the corrections to be applied to observations. The propinquity of the moon to the earth also causes her place, as seen from different places on the earth's surface, to differ from her place as seen from the centre; hence the *parallax* is a considerable correction in reducing apparent elements. The mean value of the horizontal parallax is 57′ 1·8″.

The *lunar influence* is most conspicuous in the phenomena of the tides, in the calculations of which the lunar elements occupy the most prominent place. The only other point to be alluded to is the meteorological fact of the tendency to disappearance of clouds under the full moon.

Moon, Age of.—The elapsed portion of a lunation which is the period from new moon to new moon, the average length of a lunation being 29½ days. The moon's age is given in the "Nautical Almanac", p. IV., of the month, for every mean moon at Greenwich; and hence it may be deduced for any other time and place. For many purposes it is convenient to be able mentally to calculate, without reference to books, what will be the approximate age of the moon on some future day. The following method will be found useful.

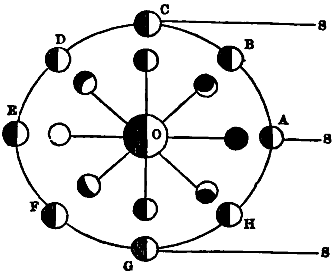
First—Obtain the *Epact for the Year*, or age of the moon on the preceding 31st December. This is given in the "Nautical Almanac", and is very nearly 11 days more each year than in the preceding; it may therefore be always practically found by adding 11 to the epact of last year and rejecting 30, if necessary.

Secondly—Obtain the *Epact for the Month*, or age of the moon at the end of the previous month, supposing the moon to change on 1st January. In January a lunation is taken as equal to 29 days, in February to 30 days; for March, May, and July, it is taken at 29 days; and for April and June, at 30 days; as a lunation is not accurately 29½ days, it is found better to distribute the error equally among the succeeding months. The figures thus obtained can be remembered without difficulty after having seen them written in three lines beneath the months, forming a pyramid, where it will be observed that the only odd figures fall below the cyphers:—

Jan. (1)	Feb. (2)	March (3)		
0	2	0		
April (4)	May (5)	June (6)	July (7)	
2	2	4	4	
Aug. (8)	Sep. (9)	Oct. (10)	Nov. (11)	Dec. (12)
6	7	8	9	10

Thirdly—*To the Epact for the Year add the Epact for the Month, and then the Day of the Month, and reject* 30, *if necessary.* Examples.—Age of moon on June 12, 1882 = 11 + 4 + 12 = 27 days; this will therefore not be a moonlight night. Age of moon on August 17, 1883 = (11 + 11) + 6 + 17 − 30 = 15; this will therefore be a moonlight night.

Moon's Phases (Gk. φάσις, "an appearance").—The moon is an opaque body, and, being illuminated on one side by the sun, reflects from its surface in all directions a portion of the light so received, and thus, as seen from the earth, presents through the course of a lunar month different aspects; these are called her phases. Let O be the earth, A, B, C, etc., various positions of the moon in her orbit, and S the sun, whose distance is so vast that rays of light to all parts of the moon's orbit are very nearly parallel. Then, wherever the moon is in her orbit, that hemisphere towards the sun will be bright, and the opposite hemisphere dark; but the face turned towards the earth will in general be partially illuminated, the remainder of the disc being only faintly visible, if visible at all. In the position A, when in conjunction with the sun, the dark part of the moon is entirely turned towards the earth at O, and the bright side from it. Here the moon is not seen from the earth; it is now said to *change*, and is called the *new moon*. When she comes to C, half the bright and half the dark hemisphere are presented to O, and the same is the case in the opposite situation G; these are respectively called the *first* and *third quarters* of the moon. Again, when at E, in opposition to the sun, the whole of the bright hemisphere is towards O and the whole of the dark side from O, and it is now *full moon.* In the position B the portion of the bright face presented to O will be less than half the disc, this visible portion increasing from A to C. Here the appearance of the moon is described as *crescent* (L. *crescens,* "increasing"). In the corresponding position H, where the moon is *waning,* her form is the same, though differently placed. When in the positions D and F, the portion of the bright face presented to O will be more than half the disc; and here the appearance is described as *gibbous* (L. *gibbus,* "a swelling").



Moon's Horizontal Semi-diameter, Augmentation of.—When a celestial body, whose distance bears a definite ratio to the radius of the earth, is in the zenith, it is nearer to the spectator by the earth's semidiameter than when it is in the horizon; hence its apparent magnitude is largest when in the zenith. This increase of apparent diameter due to increase of altitude is sensible in the case of the moon only, her distance not bearing too great a ratio to the earth's radius. The moon's semidiameter put down in the "Nautical Almanac" is computed on the supposition that the spectator is at the centre of the earth, and is the same as it would appear when in

of any spectator on the surface. When she is between the

nith, her apparent semidiameter is somewhat greater than that which is taken out of the "Nautical Almanac". The correction to be added is given in a table as "Augmentation of the Moon's Horizontal Semidiameter"; its greatest value being 18″. This correction is calculated by the formula:—

$$\text{Aug.} = 2\,\text{R.}\ \text{cosec}\,(z' - p)\sin\frac{p}{2}\,.\cos\left(z' - \frac{p}{2}\right)$$

where R = moon's horizontal semidiameter,
z' = moon's apparent zenith distance,
p = moon's parallax in altitude,
= hor. par. × cos (app. alt.).

When the sun and moon are near the horizon their magnitudes *appear* to be much greater than when they are at a considerable altitude; and so all constellations of the stars, as the Great Bear, *appear* to occupy a much larger space when in the vicinity of the horizon than when nearest the zenith. This, however, is an optical illusion, as measures taken with instruments prove.

Moon's Semidiameter, Contraction of.—When the moon is near the horizon her disc assumes an elliptical form in consequence of the unequal effect of refraction. If, therefore, a distance be observed between another body and the moon's limb when her altitude is low, before applying her semidiameter it must be corrected. Let θ be the angle which the line joining the centre of the other body and that of the moon makes with the horizon, r the moon's radius in the direction of this line, a her radius in a horizontal direction, b her radius in a vertical direction. Let A be the altitude of the moon's centre and δ the difference of refractions for altitudes $(A+b)$ and A which can be taken from the Table of Refractions. Then—

$$\text{Correction } (a - r) = \delta \sin^2 \theta.$$

$$\text{For the moon's altitude correction } (a - b) = \delta.$$

Moon's Horizontal Semidiameter and Horizontal Parallax.—The values of the semidiameter and parallax when the sun's centre is in the horizon. —See **Horizontal.**

Moon-Culminating Stars.—Stars which, being near the moon's parallel of declination, and not differing much from her in right ascension, are proper to be observed with the moon to determine differences of meridian. This is effected by comparing the differences of the observed right ascensions of such a star and the moon's bright limb at any two meridians, which varies by reason of the moon's rapid proper motion. Knowing the moon's increase in right ascension, the difference of longitude may be thus easily found. In the "Nautical Almanac" a table of these stars is given, so constructed as to supply an observer at any part of the globe with what is equivalent to corresponding observations made at Greenwich, and thus a ready method (available on shore) is furnished of at once determining the longitude.

Motion, Proper.—Strictly speaking, the proper motion of a heavenly body would be that due to its own movement as distinguished from its apparent change of place resulting from a change in the position of the spectator. The term, however, is technically used for such total motion of the body as is independent of the effects of the earth's rotation on her axis. Thus, the proper motion of the sun is his motion in the ecliptic as distinguished from his motion in a diurnal circle; though the former is the result of the earth's revolution in her orbit, just as the latter is of her rotation on her axis.

Nadir (Arabic; compare Ger. *nieder*, Eng. *nether*).—The inferior pole of the celestial horizon. It is the point of the heavens vertically under a spectator's feet, the vertex of the invisible hemisphere. The nadir is diametrically opposite to the *Zenith.* Term now but seldom used.—See **Zenith and Nadir.**

Napier's Diagram and Curve.—A method of great beauty and value for extending and utilizing the results of a limited number of observations for determining the deviation of a ship's compass. A complete Table of

Deviations may be drawn up by its aid, and it also furnishes the means of deducing by inspection the magnetic course corresponding to a given compass course or the compass course corresponding to a given magnetic course. The Diagram is engraved, and copies supplied to each of H.M. ships; and a full description of diagram and curve with their uses will be found in the "Admiralty Manual for the Deviations of the Compass".

Natural Projections.—Perspective delineations of a surface on a given plane. They are formed by drawing from the eye straight lines, indicating the visual rays, through every point of the surface to meet the plane. The original and the representation produce the same effect on the organ of vision. Examples—the orthographic, stereographic, and central projections of the sphere. Distinguished from *Artificial Projections.*—See **Projections.**

Nautical (L. *nauticus*, Gk. *ναυτικὸς*; L. *nauta*, Gk. *ναύτης*, "a navigator"; L. *navis*, Gk. *ναῦς*, "a ship").—Belonging to ships; pertaining to a seaman's business. The term is applied in a general, comprehensive sense. Thus *nautical science* includes the two branches of *navigation* and *seamanship*.

"**Nautical Almanac**" (Arabic; *al*, the article; *manah*, "to reckon").—A work published by the Admiralty for the special use of seamen. It was projected by Dr. Maskelyne, Astronomer Royal, and first published by the Board of Longitude for the year 1767; in its present approved form it appeared in 1834. The "Nautical Almanac" is brought out four years in advance, and contains all the elements required (in addition to those observed) in celo-navigation, for the practice of which it is an essential appliance. Besides the information necessary for a navigator, the "Nautical Almanac" contains the register and prediction of the phenomena which are the subjects of astronomical science generally; in fact, its full title is "The Nautical Almanac and Astronomical Ephemeris".

The "*American Nautical Almanac*" is substantially the same as that portion of our own intended for the practical use of navigators. It was first published for the year 1855. By Act of Congress, the meridian of the observatory at Washington was decreed as the American meridian for astronomical purposes, but the meridian of Greenwich was retained for all nautical purposes. This law led to the subdivision of "The American Ephemeris and Nautical Almanac", and to the publication of two separate volumes. The first contains all the information necessary for navigation, and is published three years in advance.

The title of the French Nautical Almanac is "*Connaissance des Temps*".

The Prussian Nautical Almanac, "*Berliner Astronomische Jahrbuch*", is especially valuable to astronomers for the attention given to the Ephemerides of the minor planets.

Nautical Astronomy.—Astronomy in its application to navigation. It has been usual to distinguish by this term that branch of the science of navigation which calls in the aid of astronomy to determine a ship's place by finding the zenith from observations of the heavenly bodies. The objection to its being thus applied is that it implies a branch of the science of astronomy rather than a branch of the science of navigation; "astronomical navigation" would be a more correct though a cumbrous phrase. We suggest the adoption of the term celo-navigation for this branch of the science, distinguishing the other as geo-navigation.—See **Navigation.**

Nautical Day.—See under **Day.**

Navigation (L. *navigo*, "to sail", from Gk. *ναῦς*, L. *navis*, "a ship"; Gk. *ἄγω*, L. *ago*, "to lead", "drive", "deal with").—The science which treats of the determination of a ship's place at sea, and which furnishes the knowledge requisite for taking a ship from one place to another. The two fundamental problems of navigation are, therefore, the finding at sea our present position, and the deciding our future course. There are two methods of navigation which I have distinguished as (1) *Geo-navigation*, and (2) *Celo-navigation.*

1. In *Geo-navigation* (Gk. γῆ, "the earth") the place of the ship at sea is determined by referring it to some other spot on the earth's surface, either (1) some known landmark, (2) a determinate bottom, or (3) a previously defined place of the ship. (1) The rudest manner of making a voyage (that used by savage tribes) is by *Coasting;* and this requires only local knowledge, no instruments being necessary. Among civilized nations also, when a ship is in the vicinity of land its position is found upon the same principles. In this case its actual position is often a matter of vital importance; and with a good chart, azimuth compass, and sextant, simultaneous bearings of two or more objects, or the measurement of an angle, give it with facility and precision. (2) When near, though out of sight of land, we may, if we possess the results of good surveys, determine, or help to determine, our position by consulting the depth and nature of the bottom by *Soundings.* (3) When a ship leaves the vicinity of land and stretches across the open sea, we can find its position at any time by referring it to some previous position of the ship. For this purpose we require, besides a chart of appropriate construction, a timepiece to note the interval, the log-line and glass to measure the rate of sailing, and the mariner's compass to denote the direction sailed. The mariner's compass also directs our future course. The process of thus estimating a ship's place is called *Dead Reckoning;* it has been practised in Europe since the end of the twelfth century, when the compass was introduced. The compass is, however, recorded to have been known to the Chinese in very remote ages. It has been customary to apply the term "navigation" in a restricted sense to the method we have described as "geo-navigation"; but it would be very advisable that this term "navigation" should always be used in its generic or general sense. Geo-navigation has also been called "plane sailing", but erroneously so, for though in the solutions of its problems plane trigonometry is used, the construction of the table of meridional parts, which is also required,

involves the principle of the sphere; and the rules for middle-latitude and parallel sailing are also based on the principle of the sphere. The term plane sailing should be restricted to its proper technical meaning.

2. *Celo-navigation* (L. *cœlum*, "heaven", from Gk. *κοῖλον*, "hollow"). In this method the position of the ship is determined by finding the zenith of the place from observations of the heavenly bodies, and our future course is pointed out by their bearings. For this purpose we require such an instrument as the sextant, for measuring the altitudes and taking the distances of heavenly bodies; and a chronometer, to tell us the difference in time between the meridian of the ship and the first meridian; also a precalculated astronomical register, such as our "Nautical Almanac", the "*Connaissance des Temps*" of France, or the "Berlin Ephemeris". The solution of problems relative to the celestial concave requires the use of spherical trigonometry, which, therefore, characterises in a marked manner this method of navigation. The process of estimating a ship's place by these means is called technically "By Observation", in contradistinction to "By Dead Reckoning". Celo-navigation for voyages away from land is more ancient than geo-navigation (Acts xxvii. 20). Celo-navigation has been commonly called "nautical astronomy"; but this term implies a branch of the science of astronomy, just as "nautical geography" would imply a branch of the science of geography, whereas we wish to speak of a branch of the science of navigation. We therefore suggest the adoption of the terms "Geo-navigation" and "Celo-navigation" in the place of "navigation" and "nautical astronomy"; the generic word always being "Navigation".—See further under each term. In practice, both the above methods are combined.

Neap Tides (Sax. *neafte*, "scarcity").—The smallest tides. They take place after the sun and moon are in quadrature—*i.e.* after the first and third quarters of the moon—and are the tides resulting from the action of the two bodies conflicting. Contrasted with the *neap* are the *spring tides*. —See **Tides.**

Needle.—The magnetised bar of steel in the mariner's compass; the earliest form (that used by the Chinese) being a light thin wire like a "needle." What *form* is best has been a matter of controversy, the highest authorities favouring the regular parallelopiped with its narrow dimension placed vertically. The question of *weight* is also important; it seems to be generally true that the magnetic power increases in a less degree than the friction with the increase of weight. Agate or ruby caps to the pivot are used to decrease the friction.

Nimbus (L. "The Rain Cloud").—Regarded by Howard as one of the combined modifications of cloud, and called the *Cumulo-cirro-stratus;* but considered one of the primary classes by Fitzroy.—See **Cloud.**

Noon (*Sax.*).—According to the time reckoned by, noon is the instant when the "point of definition" is on the meridian of the observer. Thus when solar time is used, *Apparent Noon* is the instant when the sun's centre is on the meridian of the observer; *Mean Noon* is when the mean sun is on the meridian. If sidereal time is used, *Sidereal Noon* is when the first point of Aries is on the meridian. Noon is regarded as the commencement of the astronomical day, as midnight is made the commencement of the civil day. Apparent noon is found at sea by observing with a sextant the moment of the sun's meridian passage.

Normal (L. *normalis*, from *norma*, "the square" used by builders).—Perpendicular. The term is used in geometry for the perpendicular to the tangent of a curve or plane at any point.

Normal Latitude.—The angle which the normal to the earth's surface at the station of the observer makes with the plane of the equator; distinguished from the *central latitude.*

Normal Centre.—The point on the earth's axis at which the vertical from the place of observation meets the earth's axis. If l be the latitude of the place of observation; then,

$$\text{Normal-centric radius} = \text{equatorial radius} \times \left(1 + \frac{1}{300} \sin^2 l\right).$$

Reference to this point is considered by Airy the most satisfactory way of treating the earth's oblateness. He applies the method in computing the corrections in lunar-distance observations.

North Point of the Horizon.—The *north* and *south points* of the horizon being the points in which the meridian line meets the celestial horizon; the north point is that which is nearest to the north pole of the heavens. When the south pole is above the horizon, the north point is the origin from which azimuths are reckoned.

North Pole of the Earth (Sax. *nord*).—The pole to which Europe is most contiguous; the other being the *south* pole.

North Pole of the Heavens.—That pole of the heavens towards which the north pole of the earth is directed; the point diametrically opposite to it being the *south pole.*

North Frigid Zone.—That zone of the earth which is contained between the north pole and the arctic circle (parallel of about 66° 32′ N.).

North Temperate Zone.—That zone of the earth contained between the tropic of cancer (parallel of about 23° 28′ N.) and the arctic circle (parallel of about 66° 32′ N.).

Northern Hemisphere.—Of the two hemispheres into which the earth is divided by the equator, the *northern* is the one in which Europe is situated, the other being the *southern.*

Northing.—The distance a ship makes good in a north direction; it is her difference of latitude when going northward. Opposed to *southing.*

Nutation.—See **Precession** and **Nutation.**

O.

o.—Of the letters used to register the state of the weather in the log-book o indicates "*Overcast—i.e. the whole sky covered with one impervious cloud*".

Oblate Spheroid (L. *oblatus*, "compressed").—A spheroid flattened or depressed at the poles; it may be conceived to be generated by the revolution of an ellipse about its minor axis. This is the form a mass of fluid matter rotating on an axis assumes, and is important as being consequently the figure of most of the heavenly bodies.

Oblique Sailing.—All problems in plane sailing whose solutions cannot be effected by the aid of a right-angled plane triangle, are treated of under the head of oblique sailing. These problems are generally concerned with the motions of more than one ship, and often occur in naval tactics, as in making a rendezvous, cruising, and chasing.

Oblique Sphere.—The sphere in that position in which the circles apparently described by the heavenly bodies in their diurnal rotation are oblique to the horizon. It is thus the motions appear to all parts of the earth, except at the poles and the equator. The *oblique sphere* is distinguished from the *right sphere* and the *parallel sphere*.

Obliquity of the Ecliptic.—The angle at which the ecliptic is inclined to the equinoctial, and which is, therefore, the distance between their respective poles. Its value is subject to a small variation of long period; on the 1st of January, 1882, it was 23° 27′ 16″·6. It follows that the axis of the earth, which is perpendicular to the plane of the equinoctial, is inclined to the plane of her orbit at an angle of 66° 32′ 43″·4, the complement of the obliquity. It is the obliquity of the ecliptic which is the cause of the variation of the seasons. [See **Seasons.**] It is also one of the causes of the variation in the length of the solar day.—See **Day.**

Observed Altitude.—The *observed* altitude of a heavenly body must be distinguished from the *apparent* altitude and the *true* altitude.—See under **Altitude.**

Observed Distance.—The *observed* distance of two heavenly bodies must be distinguished from the *apparent* distance and the *true* distance.—See under **Distance.**

Occultation (L. *occultatio*, "a hiding").—The hiding of a heavenly body from our sight by the intervention of some other heavenly body. The commencement of the occultation, the moment when the occulted body disappears behind the nearer one, is called the *Immersion* (L. *immergĕre*, "to plunge in"); the termination of the occultation, the moment when the occulted body reappears, is called the *Emersion* (L. *emergĕre*, "to come out"). [See **Eclipse.**] The two most important cases of these phenomena are the *Lunar Occultations* and the *Occultations of Jupiter's Satellites.* Particulars for each year of the occultations of the planets and fixed stars by the moon will be found in the "Nautical Almanac" in tables called "Elements of Occultations", and "Occultations visible, etc., at Greenwich"; tables and diagrams for the occultation of his satellites by the planet Jupiter are also given in the "Nautical Almanac". Occultations belong to that class of phenomena which furnish a means for determining the longitude.—See under **Longitude.**

Octant (L. *octans* "the eighth part").—A reflecting sector, the limb of which is the eighth part of the circle.—See **Sector.**

Ophiuchus (Gk. ὀφιοῦχος, "serpent-holder"; from ὄφις, "a serpent"; ἔχειν, "to hold"; L. *serpentarius*).—A constellation to the north of Scorpio; the largest star, *α Ophiuchi*, forms with *Vega* and *Altair* an equilateral triangle. Mag. 2; 1882, R.A., 17^{h} 29^{m}, Dec. + 12° 39′.

Opposition.—Two celestial bodies are said to be in opposition when their longitudes differ by 180°. Symbol ☍. Opposed to *conjunction*.

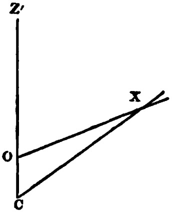
Orion (named after a mythical giant hunter).—The most brilliant constellation of the heavens, figured as a man with club and lion's skin. The stars α, β, γ, κ, are in the form of a great quadrilateral; α at the north-east angle being in the right shoulder of Orion, and the nearest to the Twins; β at the opposite angle in the left foot; γ is in the left shoulder; and κ is in the right leg. In the middle of the quadrilateral are three stars of about the second magnitude, δ, ϵ, ζ, disposed in an oblique line; these form the belt of Orion, from which depends a luminous train of small stars, called the sword. This constellation is surrounded by a series of the most conspicuous stars in the heavens—*Aldebaran*, *Capella*, *Castor*, *Pollux*, *Procyon*, *Sirius*, and *Canopus*. The equinoctial crosses near its middle. α *Orionis* (Arabic name, *Betelguese* or *Betelgeux*), mag. 1 (*var.*); 1882, R.A. $5^h\ 49^m$, Dec. + 7° 23′. β *Orionis* (Arabic name, *Rigel*), mag. 1; 1882, R.A. $5^h\ 9^m$, Dec. − 8° 20′. δ *Orionis*, mag. 2; 1882, R.A. $5^h\ 26^m$, Dec. − 0° 23′. ϵ *Orionis* is the middle star of the belt, mag. 2; 1882, R.A. $5^h\ 30^m$, Dec. − 1° 17′.

Orthographic Projection (Gk. ὀρθὸς, "straight"; γράφειν, "to grave").—The orthographic projection of the sphere is a natural projection made by straight lines at right angles to the primitive or plane of projection. The eye is conceived to be infinitely distant from the sphere, so that the visual rays are parallel to one another, and a diametral plane is chosen for the primitive.—See under **Projection.**

P.

p.—Of the letters used to register the state of the weather in the log-book, **p** indicates "*Passing showers*".

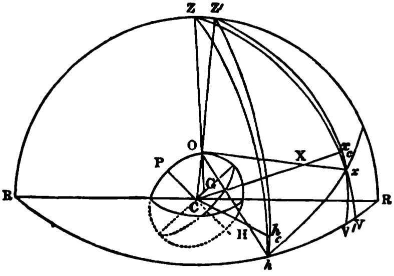
Pamperos.—Winds blowing off the Pampas, the dry terraced plains of the south-east of South America. The name properly belongs to every south-westerly wind on this coast, but European usage generally restricts it to violent westerly squalls which sometimes rotate.



Parallax (Gk. παράλλαξις, "alternation", "the mutual inclination of two lines forming an angle").—The apparent angular shifting of an object arising from a change in our point of view. It is expressed by the angle subtended at the object by a line joining the two stations. Thus, let X be the object, O and C the two points of view; then the difference of the angular position of X, with respect to the invariable direction Z′OC, when viewed from O and from C, is the difference of the angles Z′OX and Z′CX; but OXC = Z′OX − Z′CX (Euc. i. 32), *i.e.* the angle subtended at X by OC measures the apparent angular displacement of the body resulting from the change of the observer's point of view in moving from O to C. It is evident that the nearer the object the greater will be the amount of parallactic motion for any given change of the point of view. When the distance is very great in comparison with the change of the observer's station, the parallax is inappreciable, the place of the object not appearing to vary.

In astronomy the term parallax has a more technical meaning than the above. The apparent place of certain of the heavenly bodies is different as seen from different stations. It therefore becomes necessary, in order that observations made at various stations may be generalized, and put into a state to admit of their being compared with one another, that some conventional station should be fixed upon to which they may all be reduced. Parallax is defined as the *correction* to be applied to the apparent place of a heavenly body, as actually seen from the station of observation, to reduce it to its place as it would have been seen at that instant from the conventional station. There are two of these conventional centres, which are used in different cases for different purposes—the centre of the earth, and the centre of the sun. The correction for reducing the apparent place of a heavenly body as seen from the surface of the earth, to what it would have been had the observer been stationed at the centre of the earth, is distinguished as the *Geocentric* or *Diurnal Parallax*. The correction for reducing the apparent place of a heavenly body as seen from the earth in any position of her orbit, to what it would have been had the observer been stationed at the centre of the sun, is called the *Heliocentric* or *Annual Parallax*. With this latter the practical navigator has no concern.

Parallax, Geocentric or Diurnal.—This is the correction to be applied to the apparent place of a heavenly body as actually seen from the station of the observer on the earth's surface, to reduce it to its place as it would have appeared at that instant if viewed from the earth's centre. Hence it is called the *Geocentric Parallax ;* it is also entitled the *Diurnal Parallax,* because it goes through its course of variation within the time the body is above the horizon.



Let X be the heavenly body under observation, O the station of the observer on the earth's surface, C the earth's centre; let Z′ be the reduced zenith of O, then the line Z′OC is the invariable direction with respect to which the apparent angular change of position of X is referred. The place of X on the celestial concave as seen from O is x, and its place as seen from C is x_c, a point in the great circle joining Z′ and x in position above the point x. Then the angle OXC ($=p$) is the parallax of X; and since, in all cases where the geocentric parallax is appreciable, the distance of the body X vanishes compared with the distance of the celestial concave, the angle OXC ($= xXx_c$) = arc xx_c, therefore, in speaking of the parallax, either the angle OXC, or the arc xx_c, may be taken to represent it.

Let $r =$ CO, the distance of the observer from the centre of the terrestrial spheroid; D = CX, the distance of the body X from the same centre; z' the apparent reduced zenith distance of X;—then, in the triangle COX,

$$\frac{\sin \mathrm{OXC}}{\sin \mathrm{COX}} = \frac{\mathrm{CO}}{\mathrm{CX}}$$

$$\therefore \sin p = \frac{r}{\mathrm{D}} \sin z' \quad . \; . \; . \; . \; . \; . \; . \; . \quad (\alpha)$$

The parallax is generally so small that, except for the moon, no sensible error is introduced by using the circular measure for the sine;

$$\therefore p = \frac{r}{\mathrm{D}} \sin z' \quad . \; . \; . \; . \; . \; . \; . \; . \quad (\beta)$$

In the particular case of the body appearing in the horizon of the observer, the corresponding particular value of the diurnal parallax is called the *Horizontal Parallax* (= P); here $z' = 90°$;

$$\therefore \sin \mathrm{P} \text{ or (nearly) } \mathrm{P} = \frac{r}{\mathrm{D}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (\gamma)$$

and substituting this value of $\frac{r}{\mathrm{D}}$ in equation (β) we get

$$\sin p = \sin \mathrm{P} \sin z'$$
$$\text{or } p = \mathrm{P} \sin z' \quad . \; . \; . \; . \; . \; . \; . \; . \quad (\delta)$$

which is the parallax at the apparent zenith distance z', in terms of the horizontal parallax and that zenith distance.

Again, let a be the radius of the earth at the equator, e the eccentricity of the elliptic meridian of the earth, l the latitude of a place whose horizontal parallax is P, and let P_e be the *Equatorial Horizontal Parallax*, then—

$$P_e = \frac{a}{D}$$

$$\therefore P = \frac{r}{a} P_e$$

$$= P_e \sqrt{1 - e^2 \sin^2 l} \quad . \; . \; . \; . \quad (\epsilon)$$

From the above formulæ the following conclusions are drawn:—(1) From (γ) it follows that the nearer the body the greater will be the parallax. (2) For the same body (β) shows that the parallax varies as the sine of the apparent zenith distance; and hence, also, that it has a course of variation comprised within the time the body is above the horizon. (3) From a comparison of (β) and (γ) it appears that parallax is greatest when the body is in the horizon of the observer, and that it vanishes when the body is in the reduced zenith. (4) The earth's radius diminishing from the equator to the pole, we conclude from (ϵ) that the horizontal parallax decreases as the latitude of the observer increases.

Parallax, Horizontal.—The horizontal parallax is the particular value of the diurnal parallax when the body appears in the observer's horizon. It would be very desirable if the term **Horizon Parallax** could be substituted for "horizontal parallax". But the latter has the authority of the "Nautical Almanac". Let H be the position of the body X in this case, h its place in the horizon as seen from O, and h_c (a point in the great circle passing through h and Z′) the place of the body in the celestial concave as seen from C; then the angle OHC, or the arc hh_c, is the horizontal parallax (= P). The angle COH is a right angle,

$$\therefore \sin P \text{ or (nearly) } P = \frac{r}{D}$$

a formula which we deduced from the general one (β) of the last article by making $z' = 90°$. It also appeared that the horizontal parallax is the greatest value of the diurnal parallax. Again, it was shown that p, being the value of the diurnal parallax when the apparent zenith distance of the body is z',

$$\sin p \text{ or (nearly) } p = P \sin z'$$

from which p may be calculated when P is known. But as the radius of the terrestrial spheroid varies with the latitude of the observer, it is necessary to specify some standard value of P before it can be available for general use; this value is the *Equatorial Horizontal Parallax* ($= P_e$). Hence, from (ϵ), last article,

$$\sin p \text{ or (nearly) } p = P_e \sqrt{1 - e^2 \sin^2 l} \, . \sin z'$$

Thus, for example, the moon's horizontal parallax given in the "Nautical Almanac," p. iii., is the equatorial horizontal parallax. For any other place a subtractive correction must be applied to this, which is taken from a table given in works on navigation.

Parallax in Altitude.—The parallax in altitude is the parallax as it affects the altitude of the body under observation. Strictly, the diurnal parallax takes place in the great circle passing through the apparent place of the body and the *reduced* zenith (as $Z'x_c xV'$), the parallax in altitude is supposed to take place in the great circle passing through the apparent place of the body and the *true* zenith (as the vertical circle ZxV). Since, however, these two circles ($Z'x_c xV'$ and ZxV) are nearly coincident, and as the parallax (xx_c) is small, the diurnal parallax may be used without error for the parallax in altitude in all the common problems of celo-navigation. Formula (δ) thus becomes

$$\text{Parallax in altitude} = \text{horizontal parallax} \times \cos \text{altitude}.$$

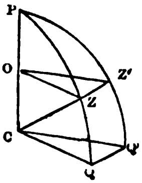
The altitude here is first corrected for refraction. From this formula tables have been computed sufficiently accurate for correcting the apparent altitude of the sun and the moon for the combined effects of parallax and refraction.

Parallax being supposed to take place in vertical circles, the term *Parallax in Altitude* is often used, in contradistinction to the *Horizontal Parallax*, to signify any value of the diurnal parallax except that which it has when the body is in the horizon.

Parallel Sphere.—The sphere in that position in which the circles apparently described by the heavenly bodies in their diurnal revolution are parallel to the horizon. This can only happen to a spectator at the poles. The *Parallel Sphere* is distinguished from the *Right Sphere* and the *Oblique Sphere.*

Parallels of the Sphere.—Lesser circles whose planes are parallel to the primitive great circle in any system of co-ordinates, each thus marking out all points which lie at the same distance from it. On the terrestrial sphere the *Parallels of Latitude* are lesser circles parallel to the equator, and each marks out all places that have the same latitude north or south. On the celestial sphere, *Parallels of Declination*, *Parallels of Latitude*, and *Parallels of Altitude* are less circles whose planes are parallel respectively to the equinoctial, the ecliptic, and the horizon, and in each case mark out respectively all points that have the same declination, the same latitude, or the same altitude.—See **Co-ordinates for the Surface of a Sphere.**

Parallel Sailing.—When the ship's track lies along a parallel of latitude. In this particular case the three canons of plane sailing are unnecessary as distance = departure, and course = 90°; but further, it is a case of spherical sailing, for the complete solution of which plane trigonometry suffices. The latitude being constant, the difference of longitude bears a constant ratio to the distance, and all problems may be completely solved by the solution of a right-angled plane triangle, and therefore by inspection of the traverse table.



Parallel sailing may be considered as the link between plane and spherical sailing; its characteristic formula is

Distance = difference of longitude × cosine latitude.

This may be proved as follows:—

Let Z and Z′ be two places, P the adjacent pole, ZZ′ the arc of the parallel of latitude passing through the two places, QQ′ the corresponding arc of the equator intercepted between their meridians. Then the sectors CQQ′, OZZ′ being similar,

$$\frac{ZZ'}{QQ'} = \frac{OZ}{CQ} = \frac{OZ}{CZ} = \sin OCZ = \cos QCZ$$

$$\therefore ZZ' = QQ' . \cos QZ, \quad \text{or, Dist.} = \text{diff. long.} \times \cos \text{lat.}$$

which, in logarithmic form, is—

$$\text{log. dist.} = \text{log. diff. long.} + \text{L} \cos \text{lat.} - 10.$$

The method of parallel sailing will apply correctly enough for all practical purposes to cases where the course is nearly east or west. In latitudes not higher than 5°, when the distance does not exceed 300 miles, the departure may be used at once for the difference of longitude, the resulting error scarcely exceeding one mile. When the means of determining the longitude were not so reliable as they are now, it was a common practice first to make the parallel of the place of destination and then sail along it east or west as required. Hence the importance formerly attached to parallel sailing.—See **Sailings**.

Parallelogram of Forces.—The most important proposition in mechanics, and one the navigator has constantly to apply.

A single force which is capable of producing the same effect on a particle or rigid body as would result from the combined action of several other forces, is called their *resultant;* and the constituent forces of the system with reference to this equivalent resultant are called ***components***.

The *Parallelogram of Forces* is thus enunciated:—If two forces acting at a point be represented in magnitude and direction by two straight lines drawn from that point, and if a parallelogram be constructed, having these two lines for adjacent sides, then that diagonal of the parallelogram which passes through the point of application of the forces will represent their resultant in magnitude and direction.

The components are generally described by the letters P and Q, and the resultant by R. As the opposite sides of the parallelogram are equal and parallel, and the opposite angles equal, problems are treated by the solution of a plane triangle. A few examples may be mentioned.

1. The wind acting on a flat sail is R, and it may be resolved into P acting perpendicular to the surface of the sail and propelling the ship, and Q acting along the surface and producing no effect.

The component P may be again resolved into two sub-components, one urging the ship forward in the direction of her length, the other causing her to make leeway.

2. The effects of a steam propeller of a vessel may be represented by P, and the action of the wind by Q; the combination will result in R.

3. The combined effect of the oars of a boat may be called P, and the action of the current Q; the resulting way of the boat will be R.

4. The magnetic influence of a ship upon a compass needle may be represented by a single force R, and this may be resolved into two components, one, P acting horizontally, and the other Q acting vertically.

Again the horizontal component may be further resolved into two sub-components, one acting fore and aft, the other athwartships.

5. A similar principle applies to velocities, an illustration of which will be found in aberration.

Pavo (L. "The Peacock").—An unimportant constellation to the south of Sagittarius, lying between the two bright stars *Antares* and *Fomalhaut.* The northernmost star is *α Pavonis ;* mag. 2; 1882, R.A. $20^h\ 16^m$, Dec. — 57° 7′

Pegasus (named after a mythical winged horse of the Greeks).—A constellation, the four principal stars of which, α, β, γ, δ, form a remarkable square; δ *Pegasi* is also called α *Andromedæ*, and the two other stars of Andromeda, β and γ, together with the adjoining β *Persei*, form, with the square of Pegasus, a group very similar to, though much more extensive than, the Great Bear lying on the opposite side of the pole. Cassiopeia lies about midway between *Polaris* and Pegasus. α *Pegasi* is the furthest from Andromeda and the westernmost of the constellation, therefore passing the meridian first, and β is at the northern angle. There are two small stars η and ξ which are parallel to this side of the square and serve to identify it. α *Pegasi* (*Markab*), mag. 2; 1882, R.A. 22^h 59^m, Dec. + 14° 34′. γ *Pegasi* (*Algenib*), mag. 3.2; 1882, R.A. 0^h 7^m, Dec. + 14° 32′. δ *Pegasi* (or α *Andromedæ*), mag. 2; 1882, R.A. 0^h 2^m, Dec. + 28° 26′.

Pelorus (the pilot of whose trustworthiness Annibal had proof, and after whom, when dead, he called the promontory now known as C. Faro. A tower was here erected to guide the sailor past the dangerous Charybdis).—See **Compass-card, Dumb.**

Perseus (named after a mythical hero, the slayer of Medusa).—A constellation lying between Auriga and Taurus on its east, and Cassiopeia and Andromeda on its west. Of its two principal stars, α lies nearly between *Capella* and Cassiopeia, β (also called β *Medusæ*) forms a triangle with *Capella* and the Pleiades. β *Persei* is remarkable for its periodic changes of magnitude. α *Persei*, mag. 2; 1882, R.A. 3^h 16^m, Dec. + 49° 26′

Personal Error or **Equation.**—Different individuals have their peculiarities which materially affect the observations made by them. The organ of vision is more refined and specially educated in one person than in another, and the forming a judgment of the exact instant of a phenomenon is greatly influenced by the temperament of the observer. The error arising from this cause is called the Personal Error, or, with reference to the consequent correction to be made to an observation, the Personal Equation. Even when two images in contact are at rest before two observers, one will decide that they overlap, and the other that they are apart; but especially when the images are in motion does such difference of opinion occur. Anxiety lest he should miss the observation may lead a nervous observer to think he sees the contact before it really takes place, while quickness of perception may be deficient in another observer. It is also found that the personal equation is not constant for the same individual at all times, but is influenced by any cause which affects the nervous system, especially the fatigue of continued observing. When accuracy is required, these circumstances should be borne in mind preparatory to observing; and observations taken by different persons should not be used in combination until cleared of the personal errors. Such corrections as this are of a refined character, and are regarded only in observations made on shore in an observatory.

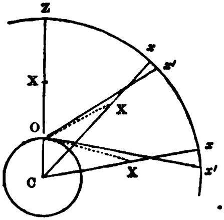
Phases (Gk. φάσις "an appearance").—The different appearances presented by the moon, the inferior planets and Mars, in consequence of varying portions of the disc, seen from the earth, being illuminated by the sun's rays.—See under **Moon, Venus.**

Phœnix (named after a mythical bird of the Egyptians).—A constellation the principal star of which, *α Phœnicis* (mag. 2.8), is situated midway between *Fomalhaut* and *Achernar*, nearly in the line joining them.

Piscis Australis (L. "The Southern Fish").—A constellation to the south of Aquarius, containing the brilliant star called *Fomalhaut.* A line through β and α Pegasi, continued more than twice their distance, gives the position of *α Piscis Australis* or *Fomalhaut;* mag. 1.2; 1882, R.A. $22^h\ 51^m$, Dec $-\ 30°\ 15'$.

Place, Geocentric and Heliocentric.—By the Place of a heavenly body is meant the point on the celestial concave to which it is referred by a spectator. This place will evidently differ according to the spectator's point of view. For the sake of generalizing observations, and putting them into a form fitted for comparison and turning them into practical account, it therefore becomes necessary to agree upon some conventional centre, and reduce all observations made at various stations to what they would have been had they been made at this centre. There are two such conventional stations used by astronomers—the centre of the earth, and the centre of the sun. The place of a heavenly body, as viewed from the centre of the earth, is called its *Geocentric Place* (γῆ, "the earth"); the place of a heavenly body, as viewed from the centre of the sun, is called its *Heliocentric Place* (ἥλιος, "the sun").—See **Parallax.**

Place, Apparent and True.—The Apparent Place of a heavenly body is the point on the celestial concave to which it is referred by an observer from a station on the earth's surface viewing it through the atmosphere. The True Place of a heavenly body is the point on the celestial concave to which it would be referred by an observer at the centre of the earth viewing it through a uniform medium. Let C be the centre of the earth, O the observer's station, X a heavenly body. Draw Ox' the tangent to the visual ray from X meeting the celestial concave in x', and join CX and produce CX to meet the celestial concave in x; then the projections x' and x are respectively the apparent and true places of X. They differ most when the body is in or near the horizon, and coincide when it is in the zenith. The true place is obtained from the apparent place by applying the corrections for refraction and parallax, the former of which causes a body to appear higher, the latter lower than its true place. These two cor-

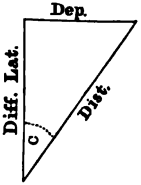


rections are thus combined, but the difference in the nature of refraction and parallax must not be therefore forgotten; in consequence of refraction the object is not actually in the position to which it seems to be; parallax is merely a reduction of the observations made at one place to what they would have been if made at another. Refraction is independent of the distance of the body, but parallax increases with the proximity of the body. When the body is very near, like the moon, parallax tends to depress more than refraction to raise, and therefore the moon's apparent place is lower than her true place. On the contrary, for more distant bodies, such as the sun and planets, refraction raises more than parallax depresses, and therefore the apparent place of these bodies is higher than the true place.

Place of Ship.—See under **Position.**

Plane Chart.—A chart constructed on the supposition that the earth is an extended flat surface. The meridians are depicted as parallel right lines, and the parallels of latitude at right angles to the meridians; the length of degrees on the meridians, equator, and parallels of latitude are everywhere equal, the degrees of longitude being reckoned on the parallels of latitude as well as on the equator. This delineation represents very nearly the relative directions and distances of places near the equator, and serves for plans of ports and seas in those regions. For higher latitudes it exhibits truly no directions but N. and S., E. and W., and no distances but those measured on the meridian, and hence the figure of every portion of the surface, however small, is distorted. The use of these charts is obsolete.

Plane Sailing.—The method of solving, or partially solving, problems in navigation on the supposition that the path of the ship is described on a plane surface; it is opposed to *spherical sailing*, which takes account of the elements affected by the spherical form of the earth's surface. Plane sailing requires the use of plane trigonometry only; spherical sailing calls in the aid of spherical trigonometry, either in the actual computation or in the construction of the tables used. The two general problems of navigation are: 1st, Given the latitudes and longitudes of two places, required the course and distance from one to the other; and 2nd, Given the latitude and longitude of a place, and the course and distance from this to another place, required the latitude and longitude of the latter. If we attempt completely to solve these problems on the principles of plane sailing, a *plane chart* must be used—*i.e.* a chart in which the meridians are depicted as parallel right lines, the parallels of latitude drawn at right angles to the meridians, and the length of the degrees on the meridians, equator, and parallels of latitude are everywhere equal, the degrees of longitude being reckoned on the parallels of latitude as well as on the equator. The results thus obtained would be very erroneous, except where the track of the ship lay near the equator, If, however, besides the above element—course, distance, difference of latitude, and difference of longitude—we introduce another, the departure, the problems of navigation may in every case be solved *to a certain point* on the principles of plane sailing. In rhumb sailing, the course being constant, the difference of latitude and departure are proportional to the distance on the sphere as they would be on a plane; these three elements may therefore be represented by the sides of a right-angled plane triangle, of which one of the angles is the course. Hence, in the general solution of the problems of navigation, plane sailing furnishes us with the following relations between the course, distance, difference of latitude, and departure, which are sometimes called the "Canons of Plane Sailing":—



1. $\text{Dep.} = \text{dist.} \times \sin \text{course}$

$\therefore \log. \text{dep.} = \log. \text{dist.} + \text{L} \sin \text{course} - 10.$

2. $$\text{Diff. lat.} = \text{dist.} \times \cos \text{course}$$
$$\therefore \log. \text{diff. lat.} = \log. \text{dist.} + \text{L} \cos \text{course} - 10.$$

3. $$\text{Dep.} = \text{diff. lat.} \times \tan \text{course}$$
$$\therefore \log. \text{dep.} = \log. \text{diff. lat.} + \text{L} \tan \text{course} - 10.$$

The solution of the right-angled triangle, of which these quantities are the elements, may be effected by inspection by the use of the *Traverse Table.* There is, however, no constant proportion between the departure and the difference of longitude in different latitudes; and, therefore, problems in which difference of longitude is concerned are beyond the province of plane sailing, except when the ship is near the equator, where the departure and difference of longitude may be for practical purposes considered equal. The principles of plane sailing are conveniently applied in coasting or making land, when a plane chart may, without error, be used. It enables us at once to *resolve* the distance run on any given course into the distance upon a proposed course, and thus to determine, for instance, the rate at which a ship is approaching a proposed port. When the ship makes several courses in succession, we have what is called *Traverse Sailing*, which consists in finding a single resultant for the several courses and distances. In *Current Sailing* a resultant has to be found for two simultaneous courses and distances. *Oblique Sailing* is a term applied to those cases for the determination of which an oblique triangle has to be solved. The above is the accurate use of the term "Plane Sailing", but it is sometimes loosely used as a synonym for the equally ill-used term "Navigation", as contrasted with "Nautical Astronomy". It is thus made to include "Mercator Sailing"; but although Mercator sailing apparently requires the application of plane trigonometry only, the table of meridional parts, the use of which characterises it, involves the principle of the sphere. The term plane sailing should be restricted to its proper signification.—See **Sailings.**

Planets (Gk. *ἀστὴρ πλανήτης*, "a wandering star", from *πλανᾶσθαι* "to wander").—This term originally described all the heavenly bodies which were observed to change their place in the celestial concave, in contradistinction to those whose position appeared to be fixed. The word, however, is now technically restricted to indicate those moving bodies of a character similar to our own globe, which revolve in orbits about the sun of our system. They shine by the reflection of light received from the sun. The principal planets, in the order of their distances from the sun, with their symbols, are—Mercury ☿, Venus ♀, the Earth ⊖ or ♁, Mars ♂, ... Jupiter ♃, Saturn ♄, Uranus ♅, Neptune ♆. Besides these, near to the sun a small planet named Vulcan has been reported, and between Mars and Jupiter is a group of minute planets, called the *Asteroids* or *Planetoids;* they are very numerous, between eighty and ninety having been already detected and named. The paths of the principal planets are in planes making a small angle with the plane of the ecliptic. The planetary motions are governed by the three following laws, called, after their discoverer, Kepler's Laws: (1) The planets move in ellipses, each having the sun's centre in one of its foci; (2) The areas swept out by each planet about the sun are, in the same orbit, proportional to the time of describing them; (3) The squares of the periodic times are proportional to the cubes of the major axes. It must, however, be borne in mind that, strictly speaking, the centre of the sun is not a fixed point, the motion taking place about the centre of gravity of the whole system; this point, however, is very near the centre of the sun. Again, the planets mutually attract each other, and this causes perturbations of their several orbits.

To the practical navigator the actual dimensions and movements of the planets are not so important as the conspicuous phenomena they exhibit. Four of them—Venus, Mars, Jupiter, and Saturn—are remarkably large and brilliant bodies, and of great importance in the problems of celo-navigation; another, Mercury, is also visible to the naked eye as a large star, but, by reason of its propinquity to the sun, is seldom conspicuous; Uranus is barely discernible without a telescope; the rest are never visible to the naked eye. Venus and Jupiter are seen very distinctly during twilight, and this is the best time for observing them, for then the horizon is in general clearly visible and strongly marked. Observations of these two planets may often be obtained in the daylight, even when the planets are invisible to the naked eye. The meridian altitude of Jupiter may sometimes be thus observed with advantage. It is first approximately computed—the corrections for refraction, dip, and index-error being applied reversely; this angle is then set on the sextant, the inverting telescope being screwed close down to the plane of the instrument. The image of the planet will be by this means detected near the N. or S. point of the horizon, and, once found, its meridian altitude may be accurately observed. The four planets, Venus, Mars, Jupiter, and Saturn, are used for determining the longitude by the method of "lunar distances." It is, therefore, important to know how to identify these bodies. They are collectively distinguished from the fixed stars by their shining with a steady light, instead of twinkling. By reason of their proper motion they are continually shifting their place in the celestial concave, and cannot be connected by imaginary lines with other heavenly bodies, as in the case of the fixed stars. Their position at any time may, however, be found with the aid of the "Nautical Almanac", which gives their right ascension, declination, and the time of Greenwich meridian passage. We may hence find the planet's meridian altitude at the time of its transit over the meridian of observation, or we may find in what constellation it is situated, or ascertain its position with respect to some bright star near it at the time. The appearance of the body itself may also help to determine which planet it is; Venus has a bluish light, while Mars is of a red colour. Venus and Jupiter are the brightest; but the former, which is an inferior planet, is never seen more than 47° from the sun, while Jupiter is seen at every distance from the sun.

Planets, Inferior and Superior.—Those planets whose orbits are within that of the earth are called *Inferior Planets;* those whose orbits are external to that of the earth are called *Superior Planets.* The inferior planets are Vulcan, Mercury, and Venus; the superior planets are Mars, the Asteroids, Jupiter, Saturn, Uranus, and Neptune. The phenomena exhibited by these two classes, to an observer on the earth's surface, are in many respects different. The *elongation*, or the angle subtended at the earth by a planet's distance from the sun, in the case of the inferior planets, can never exceed a certain limit. Mercury, owing to its nearness to the sun, is seldom visible; Venus, when to the west of the sun, is seen in the east a little before sunrise, and is then called the *Morning Star;* at other times, when to the east of the sun, it is seen in the west just after sunset, and is then called the *Evening Star*. There is, on the other hand, no limit to the elongation of the superior planets, and therefore no connection between the times of their rising and setting and that of the sun; they are seen at all hours of the night, and at various altitudes above the horizon. Again, a *transit* over the sun's disc can only occur in the case of an inferior planet. And, finally, the inferior planets present to the earth *phases* like those of the moon; the superior planets (with the exception of Mars, which sometimes presents a slightly gibbous appearance) have no perceptible change of phase. All the planets, as seen from the earth, are alternately direct and retrograde in their motions. An inferior planet always appears to be moving forwards ("direct", in the order of the signs) when in the conjunction furthest from the earth; and backwards ("retrograde", contrary to the order of the signs) when in the conjunction nearest to the earth. Similarly a superior planet always appears to be moving forwards when in conjunction, and backwards when in opposition.

Planets, Primary and Secondary.—In the solar system there are at least twenty moons or satellites, and these are sometimes called *Secondary Planets;* hence the planets themselves about which these resolve are distinguished as *Primary Planets*. The two simple words *Planets* and *Satellites* are the most convenient names for the two classes of bodies.

Pleiades (Gk. πλειάδες).—A very conspicuous cluster of seven small stars, six of which are visible, in the constellation Taurus. This group is a very convenient mark to help the seamen in identifying bright stars in its vicinity. It is also of historical interest to the navigator. The ancient astronomers connected the seasons with the position of stars relatively to the sun at his rising and setting. A star was said to rise *heliacally* (ἥλιος "the sun") when after being in conjunction with the sun, and consequently invisible, it rises so much before him as to be visible in the eastern horizon in the morning twilight; and it was said to set heliacally when the sun approaches so near to it that it is extinguished in his light or ceases to be visible in the western horizon after he has disappeared. The word Pleiades is derived from πλέω "to sail the sea", because the season of Greek navigation began at its heliacal rising.

P.M.—The initials of *Post Meridiem* (L.), "after noon"; opposed to A.M., *Ante Meridiem*, "before noon".

Pointed Sun.—When an observation is taken with a reflecting sector, the sun seen by direct vision is called by Raper and others "the pointed sun"; a better term is "the direct sun".

Pointers.—The two bright stars β and α *Ursæ Majoris*, are called the "Pointers", because they point out Polaris, which lies at about the same distance from α as α does from η, the extreme star in the tail of the Great Bear.

Points of the Compass.—The circumference of the compass card, which represents the horizon of the spectator, is divided into 32 equal parts called points. As in the whole circumference there are 360°, there are in each point 11° 15′. The point is sub-divided into *Half-points* (each 5° 37′ 30″) and *Quarter-points* (each 2° 48′ 45″).

Polar Angle.—On the terrestrial sphere, the angle at the pole formed by two meridians; on the celestial sphere, the angle at the pole formed by two hour-circles.

Polar Circles.—The two parallels of latitude encircling the poles at the same distance from them that the tropics are from the equator—viz. about 23° 28′; they are, therefore, the parallels of about 66° 32′ N. and S. We say "about", because their positions go through small periodic changes. The *North Polar Circle* is called the *Arctic Circle*, from the great constellation which is situated within the parallel of declination of about 66° 32′ N.—the "Bear" (ἄρκτος); and the *South Polar Circle* is distinguished as its opposite, the *Antarctic Circle*. They mark the limits of those zones within which the sun does not set in the interval between at least two or more consecutive culminations. These spaces are called the Frigid Zones, and are divided by the polar circles from the Temperate Zones.

Polar Distance.—The polar distance of a heavenly body is its angular distance from the elevated pole of the heavens; it is measured by the intercepted arc of the hour-circle passing through it, or by the corresponding angle at the centre of the sphere. Sometimes polar distances are reckoned from the nearest pole from 0° to 90°, but this plan is attended with inconvenience. Again, the polar distance is the complement of the declination, and declinations are frequently regarded positive (+) or negative (—) according as the object is situated in the northern or southern celestial hemisphere; in this case, all ambiguity is avoided by reckoning polar distances from the north pole from 0° to 180°. But the most convenient method of reckoning polar distances is *from the elevated pole towards the depressed one from* 0° *to* 180°. According as the north or south pole is elevated we have the *North Polar Distance* or the *South Polar Distance.* The hour-angle and polar distance are the polar coordinates for defining points of the celestial concave, and indicating their position relatively to the place of an observer on the earth's surface.—See **Hour-Angle** and **Polar Distance.**

Polaris (L., understand *Stella*, star) or **Pole Star.**—The pole-star of a planet is the bright star towards which its axis of rotation is directed at any epoch. With reference to the earth the star *α Ursæ Minoris* is so called from its being the bright star which is nearest to the north pole of the heavens. Its Arabic name is *Ruccabah*, and it is also known as the *Cynosure* (from *κύων*, *κυνὸς*, "a dog", and *οὐρὰ*, "the tail"—the constellation of *Ursa Minor* being anciently figured as a dog). Polaris can readily be found by the "Pointers" *β* and *α Ursæ Majoris*, being the first bright star which the line of their direction passes. *α Ursæ Majoris* (*Dubhe*) is at the same distance from the stars in the extremities of the two constellations, the Great Bear and the Little Bear, the former being *η Ursæ Majoris*, and the latter *α Ursæ Minoris* or *Polaris*. The star *α Ursæ Minoris* has not always been and will not always continue to be the Pole star. The precession of the equinoxes involves a very slow motion of the pole of the heavens among the stars in a small circle round the pole of the ecliptic. The effect of this is an apparent approach of some stars to the pole and recess of others. When the earliest catalogues were constructed, the present Pole star was 12° from the pole; it is now less than 1½°, and will approach to within ½°, when it will begin to recede and give place to others. To take longer periods: When the Great Pyramid of Ghizeh was built (nearly 4000 B.C.), by looking down its narrow entrance passage (whose slope inclines 26° 41′ to the horizon) *α Draconis* was seen at its lower culmination—a pole star about 3° 44′ from the pole. After the lapse of 12,000 years, *α Lyræ*, the brightest star in the northern hemisphere, will be the pole star, approaching to within about 5° of the pole.

The *north pole of the heavens* may be found thus:—Draw a line from *ε Ursæ Majoris* (the first of the three stars of the tail) to Polaris, and produce it about 1½°. It is convenient for the navigator thus to know the position of the pole with respect to Polaris. When *ε Ursæ Majoris* is six hours from the meridian (which can be estimated with sufficient exactness by the eye, or more definitely obtained from a transit table) the Pole star is at its greatest distance also from the meridian. In this position of

Polaris its altitude will be nearly the same as that of the pole which is equal to the latitude of the observer. In any other position, with the aid of tables the observed altitude of Polaris may be reduced to the meridian altitude, and thus the altitude of the pole deduced and the latitude of the observer expeditiously found. Such tables are given in the "Nautical Almanac", which also furnishes other useful information respecting this most important star. Mag. 2; 1882, R.A. $1^h 15^m$, Dec. + 88° 41′.—See **Latitude.**

Poles (Gk. πόλος, "a pivot" on which everything turns, the axis of the sphere).—The points at the extremities of the axis of the celestial sphere, which in the diurnal revolution appear stationary, and about which the whole of the heavens appears to turn as upon pivots. This is the primary use of the term. Hence it was extended and applied to the extremities of the axis of the earth about which it rotates; hence, also, its more purely geometrical uses. Thus the motion of every circle of the celestial sphere whose plane is perpendicular to the axis of rotation is referred to these stationary points, which are therefore generally called the "poles" of all circles, every point of which is equally distant from each of them, and in particular they are the poles of the great circle of such a parallel system. For example, we have the "poles of the equator", the "poles of the equinoctial", the "poles of the ecliptic", the "poles of the horizon", and of their several systems of parallels. The term is still further extended to physics. Thus, when it was found that the magnet was not always directed to the north pole, but to another point, this was naturally named the "magnetic pole".

Poles of the Earth.—The two points in which the axis of the earth meets the surface. They are distinguished as the *North Pole* and *South Pole*—the former being the one nearest to Europe, the latter that most remote from it. The poles of the earth are poles of the equator.

Poles of the Heavens.—The two points of the celestial concave in which the axis of the heavens is conceived to meet its surface. The poles of the heavens are distinguished as the *North Pole* and *South Pole*—the former being that towards which the north pole of the earth is directed, the latter that towards which the south pole of the earth is directed. The axis of the earth, always remaining parallel to itself throughout her annual revolution round the sun, is considered always to be directed to the same points—the poles of the heavens; for great as the earth's orbit actually is, it vanishes relatively to the infinite distance of the celestial concave.

Pollux.—The name of the bright star β *Geminorum.*—See **Gemini.**

Position of Ship.—The position of a ship at sea is in general defined by the intersection of two determinate lines on the earth's surface, on both of which the ship is ascertained to be. Different systems of these pairs of lines give rise to various methods of determining the position of the ship. (1) A *parallel of latitude* and *meridian* are the pair of lines most systematically adopted, the latitude giving the former, the longitude the latter. (2) A *parallel of latitude* and a *constant rhumb line* were used more frequently before chronometers were constructed with sufficient perfection to furnish an easy means of finding the longitude. (3) *Two lines of equal altitude* furnish a very pretty method of finding the ship's place. [See **Sumner's Method.**] (4) When the ship is in sight of land, *cross bearings* furnish the pair of lines required. The position of the ship is always registered by its latitude and longitude.

Position, Parallels of.—A name sometimes used for "*Circles of Equal Altitude*", the curves giving the position of the ship in Sumner's method. We would suggest for them another synonymous term which perhaps best embodies their distinguishing characteristic, though having reference to the celestial sphere, viz. **Zenith Parallels.**

These circles belong to a terrestrial system, determined, however, by a particular heavenly body at a definite moment, giving the pole. Each curve is the *locus* of places whose zenith is at the same distance from this pole.

The *great circle* of the system is the *Terminator*, and (the ordinary corrections being made) this is the boundary of the hemispheres, in one of which the body is visible and in the other invisible. From any point of the terminator the body will appear in the horizon.

The *pole* of the terminator is the spot in whose zenith the body is situated; and this is the only place where it has an altitude of 90°.

If *small circles* be drawn *parallel* to the terminator, each will mark out all the places on the earth's surface where the body is seen at the same altitude; these are what are called *Circles of Equal Altitude*, *Parallels of Position*, or *Zenith Parallels*. Each term is appropriate from its special point of view.

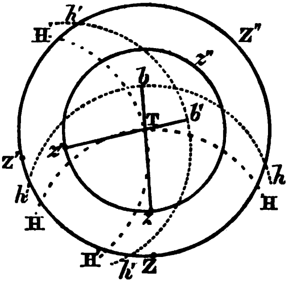
A secondary great circle to the terminator will give the *line of bearing* of the body from any particular spot on a parallel. The term "Line of Bearing" has been used for the direction of the curve of position passing through two adjacent spots projected on a Mercator's chart, but we think very unwisely.

For the sake of clearness of conception, we may compare the pole of the terminator with that of the equator and to that of the horizon. The pole of the equator is a fixed point on the earth's surface, and is independent of the position of the spectator and of any heavenly body observed; the pole of the horizon simply marks the position of the spectator, and moves with him; the pole of the terminator is dependent on the heavenly body observed, and is defined by the vertical from its place to the earth's surface at any particular moment.

The two systems, of the horizon and terminator, are frequently confused, and they demand therefore some further consideration in connection with each other. Two points must be borne in mind:—First, that the horizon system has properly reference to the celestial concave, while the terminator system is concerned with the terrestrial sphere; secondly, having substituted for the elements of the terminator system their celestial counterparts, the two systems are properly described as complementary. The pole of one system is always on the great circle of the other; and the great circle ordinate of one is equal to the polar distance of the other.

The confusion we have referred to arises from the application to a system on the terrestrial sphere of a term (" Parallels of Equal Altitude") already appropriated to a system of the celestial concave; the two not even corresponding to each other. ***Parallels of Altitude*** are small circles of the celestial sphere parallel to the horizon; ***Parallels of Position*** are small circles of the terrestrial sphere parallel to the terminator; the term ***Zenith Parallels*** are the counterparts of the latter on the celestial concave, and serves to connect the two conceptions.

The annexed figure may serve to illustrate the terms:—The centre T is the pole of the terminator ZZ'Z"; the horizons of all the points ZZ'Z", ... viz. HTH, H'TH', ..., passing through T. The small circle *zz'z"* is the parallel 30° distant from T; the body in the zenith of T having an altitude of 60° from every point on this parallel. The line of bearing at *z* is *z* T *b*, at right angles to the curve at *z*.

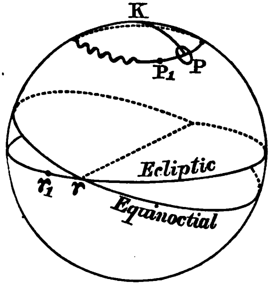


Post Meridiem (L. "after noon", abbreviated P.M.)—The designation of the latter twelve hours of the civil day—those, viz. following the sun's passage of the meridian. The other twelve are distinguished as the hours *Ante Meridiem*, "before noon".

Precession of the Equinoxes.—The equinoctial points have a slow b ward movement (from east to west) along the ecliptic. In consequence of this retrogression of the first point of Aries, the epoch of the equinox "precedes", or is earlier than it would otherwise have been.—See following article; and **Equinoctial Points.**

Precession and **Nutation** (L. *præcedo—ssi*; It. *precessione*, "a going before"; L. *nutatio*, "a nodding").—Corrections which reduce the place of a heavenly body to fixed and determinate celestial circles. The co-ordinates, which define the position of the stars, are found to undergo continual variations, which affect all the stars, and cannot, therefore, be referred to any "proper motions". They arise from a displacement of the planes and circles to which the bodies are referred. The two primary planes used are the ecliptic and the equinoctial, and the origin of co-ordinates is determined by the line of their intersection. The ecliptic is found to be very nearly a fixed plane, its position, however, being disturbed by planetary influence, which very slightly affects the right ascensions of the stars. But the luni-solar attraction on the protuberant equatorial mass, forming the excess of the terrestrial spheroid above its inscribed sphere, is considerable, and it causes the line of intersection of the equinoctial and ecliptic to have a gradual retrograde motion, the first point of Aries moving backwards along the ecliptic at a yearly rate of 50·38″. The attractions of the planets tend to alter the plane of the earth's orbit. We may consider the combined result as increasing the longitudes of all stars by a common mean quantity 50·2″ per annum, which is called the *general precession*. Again, owing to the variable action of the moon, the inclination of the equinoctial to the ecliptic undergoes small periodical fluctuations about a mean value, the cycle being identical with the variations in the luni-solar precession. These subordinate motions are named *nutation*.

The relative changes in the planes of the two great circles may best be exhibited by the consequent alterations in the place of the pole of the equinoctial with reference to the pole of the ecliptic. The effect of precession is to cause the mean place of the pole of the equinoctial P_1 to describe a small circle, with radial arc KP equal to the obliquity, round the pole of the ecliptic K, in about 25,800 years. The effect of nutation is to cause the true pole of the equinoctial to describe a small ellipse about its mean place P; with major axis 18·5″ pointing to K, and minor axis 13·7″, the revolution being completed in 18 years 220 days. The resulting true path of the pole will be a wavy curve.



In the figure ♈ is the position of the first point of Aries at the beginning of any tropical year, and ♈$_1$ its position at the beginning of the next, ♈ ♈$_1$ being 50·2″ measured backward, *i.e.* in the direction opposite to the sun's motion. By this retrogression the tropical year is shortened, and the return of the sun to the equinox takes place earlier than it would otherwise have done, hence the term *precession of the equinoxes*.

P and P_1 are the positions of the pole of the equinoctial corresponding to ♈ and ♈$_1$. This explains how different stars occupy at different eras the post of polar star.

"**Pricking the Ship off.**"—Marking the ship's position on the chart. This is always done at noon, when the account of the reckoning for the twenty-four hours is closed; and also at 8 P.M., when the course is shaped for the night.

Prime Vertical (L. *primus*, "first").—That vertical circle which passes through the east and west points of the horizon. Its poles are therefore the north and south points, and its plane is perpendicular not only to that of the horizon, but also to that of the meridian. The ordinary definition is—The prime vertical is the vertical circle at right angles to the celestial meridian. We prefer, however, the one we give for the following reason — The vertical circles, having regard to the diurnal motion of the heavenly bodies, and especially to that portion of it when they are above the horizon, and the east and west points being the points of reference for their rising and setting, the vertical circle which passes through these points holds naturally the first place among the vertical circles. The prime vertical is among the vertical circles of the heavens what the first meridian is among the meridians of the earth. The word "prime" may, however, have direct reference to the *east* point as being the point of reference for the *prime* or *rising* of the heavenly bodies. To a spectator at the equator all the heavenly bodies rise perpendicularly to the horizon, but it is only those that rise at the east point which perform a great circle in their diurnal course—viz. the prime vertical.

Primitive Plane (L. *primitīvus*, "the first of its system").—In projections the primitive plane is that on which the surface to be represented is delineated.

Prismatic Compass.—A compass so fitted that, when a bearing is observed with it, the graduation of the card is read off by reflection from the interior surface of a prism. This prism is a solid piece of glass, whose sides are parallelograms and ends triangles.—See under **Compass.**

Procyon (Gk. *προκύων*; from *προ*, "before"; *κύων*, "a dog"; so called from its rising before the Dog-star Sirius).—The proper name for the "lesser dog-star," *a Canis Minoris.*—See **Canis Minor.**

Projection (L. *projectio*, "a throwing forward").—A delineation of a proposed figure on a given surface, formed by means of lines drawn according to some definite laws. The projection of a surface is generally conceived as made by straight lines, and on a plane. This plane is called the "Primitive Plane". A distinction is also drawn between *Natural* and *Artificial* projections. (1) A *Natural Projection* of a surface on a given plane is such a delineation of it as would be formed by drawing straight lines from the eye in a definite position through every point of the surface to meet the plane, the original and the representation producing the same effect on the organ of vision. (2) An *Artificial Projection* is a delineation of the surface on a plane traced according to fixed laws, not being a perspective representation.

Projections of the Sphere.—Delineations of the surface of the sphere on a plane made according to definite laws, and furnishing the means of constructing maps and charts. Projections of the sphere are either *Natural* or *Artificial*.

1. Natural Projections of the sphere are delineations of the surface on a plane, defined in position, representing the sphere as it appears to the eye situated at a given point. According to the relative positions of the sphere, the eye, and the primitive or plane of projection, there are different methods of natural projection, the three most important of which are the *Orthographic*, *Stereographic*, and *Central* or *Gnomonic*. (*a*) In the *Orthographic* the eye is indefinitely distant from the sphere, so that the visual rays are parallel to one another, and the primitive is perpendicular to their direction; (*b*) in the *Stereographic* the eye is situated on the surface of the sphere, and the primitive passes through the centre so as to have the eye in its pole; (*c*) in the *Central* or *Gnomonic* the eye is at the centre of the sphere, and the primitive is a tangent plane.

Projections of the sphere, on whichsoever of the above methods they are made, are further named *Equatorial*, *Meridional*, or *Horizontal*, according as the primitive coincides with or is parallel to the equator, the meridian, or the horizon. All perspective representations of the sphere distort those parts which are not projected near the centre of the primitive. Thus, in a map on the orthographic projection, countries at a distance from the centre of the primitive are unduly contracted, while the reverse is the case in maps on the central projection. In maps or charts of small portions of the earth's surface this is of little consequence, as the middle of the map may always be taken for the centre of the primitive; but for extensive tracts the distortion near the edge of the map is considerable, and constitutes an objection.

2. Artificial Projections of the sphere are delineations of the surface on a plane traced according to fixed laws, not being perspective representations. *Mercator's chart*, which is that of the greatest importance to the navigator, is an artificial projection. Here the meridians are parallel straight lines equidistant from each other, the parallels of latitude are perpendicular to the meridians at such distance from each other, increasing from the equator, that the measures of a degree of longitude and latitude at any point of the projection shall have the same ratio as exists between their measures on the surface of the sphere at the corresponding point. This projection gives a true representation as to *form* of every particular small tract, but varies greatly in point of *scale* in its different regions, the polar portions in particular being extravagantly enlarged, and the whole map even of a single hemisphere not being comprisable within any finite limits.—See under **Mercator.**

Projection, Central or Gnomonic (Gk. γνώμων, "the style" or index of a dial).—A natural projection on a tangential plane as primitive, the eye being at the centre of the sphere. It is called the "gnomonic" projection, as being that used in the construction of the sun-dial. The designation "central" would seem to be the preferable one, as marking the characteristic feature in the manner of making the projection, and not merely embodying one of the practical applications of its principle. The most important properties of this projection are: (1) Every great circle of the sphere, since its plane passes through the eye, is projected into a straight line; (2) Every small circle of the sphere is projected into a conic section—an ellipse when it lies entirely on the same side of the diametral plane parallel to the primitive, a parabola when it touches that plane, and a hyperbola when it intersects that plane. In the case of the original circle being parallel to the primitive, its projection will be a circle concentric with the primitive. The first property mentioned renders charts on this projection very convenient for great-circle sailing. An entire hemisphere cannot be thus represented, as the circumference which terminates it is on a level with the eye parallel to the primitive plane. The method, however, is applicable for maps of the circumpolar regions of the earth, but as countries recede from the centre they become to a considerable degree unduly enlarged. The whole sphere is conveniently projected on the six sides of a circumscribing cube; and the maps of the earth and of the stars, published by the Society for the Diffusion of Useful Knowledge, are drawn in this manner (fig. 1).

Fig. 1.

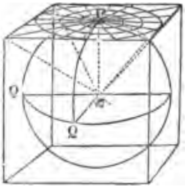


Fig. 2.

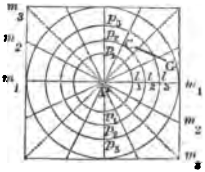


Fig. 2 represents an equatorial central projection of the terrestrial sphere: P the pole (centre of the tangential plane parallel to the equator); m_1m_1, m_2m_2, m_3m_3, ... meridians; $p_1l_1p_1$, $p_2l_2p_2$, $p_3l_3p_3$, ... parallels of latitude; GC an arc of a great circle.

Projection, Orthographic (Gk. ὀρθὸς "straight", "upright"; γράφειν, "to grave").—A natural projection made by straight lines at right angles to the primitive or plane of projection. The eye is conceived to be infinitely distant from the sphere, so that the visual rays are parallel to one another, and a diametral plane is chosen for the primitive (fig. 1). A circle of the sphere as thus projected is an ellipse whose axis major = diameter of the circle, and axis minor = (axis major) × (cos inclination of the circle to the primitive). When the circle is parallel to the primitive, the projection is an equal circle; when it is perpendicular to the primitive, its projection is a straight line equal to its diameter. In maps and charts on this projection, regions at a distance from the centre of the primitive are unduly contracted; and hence, though very useful for small portions of the globe, it is of little service for large tracts. The orthographic projection is convenient in astronomy for the delineation of eclipses and the transits of the heavenly bodies.

Fig. 1.

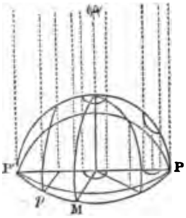


Fig. 2.

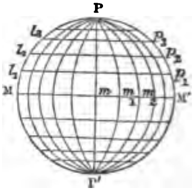


Fig. 2 represents a meridional orthographic projection of the terrestrial sphere; PMP'M', meridians—primitive plane; Pm, Pm_1, Pm_2, ... meridians; MM' equator; p_1l_1, p_2l_2, p_3l_3, ... parallels of latitude.

Projection, Stereographic (Gk. στερεὸς, "solid", "cubic"; γράφειν "to grave").—Strictly speaking, the word "stereographic" is applicable, in a general sense, to every perspective representation of a solid on a plane; but in the case of the sphere it has a limited technical sense, being confined to one method, and distinguishing a particular projection from others, such as the "orthographic" and "central." The stereographic is a natural projection of the concavity of the sphere on a diametral plane as primitive, the eye being placed on the surface at the opposite extremity of the diameter, perpendicular to the primitive (fig. 1). Its most important properties are: (1) All circles of the sphere are projected either into straight lines or circles; (*a*) those which pass through the eye into straight lines; and (*b*) those which do not pass through the eye into circles, being the sub-contrary sections of cones whose common vertex is the eye, and bases the circles to be projected. (2) The angle of intersection of two circles on the sphere is the same for their projections; hence also every very small triangle on the sphere is represented by a similar triangle on the projection. The first property mentioned renders the construction of maps on this projection very simple; the second shows that the meridians and parallels of latitude intersect each other at right angles as they do on the globe, and this also facilitates the construction of maps. Again, it is a consequence of the second property that the projection preserves a general similarity to the reality in all its parts. In receding from the centre, the dimensions are somewhat unduly enlarged, but a hemisphere may be projected without any very violent distortion of the configurations on the surface from their real forms.

Fig.1.

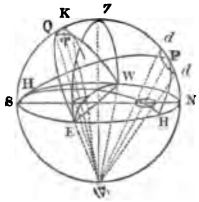


Fig. 2.

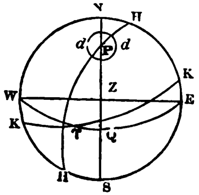


Fig. 2 represents a horizontal stereographic projection of the celestial concave: NESW, horizon—primitive plane; Z, zenith—pole of primitive plane; NS, meridian; EW, prime vertical: EQW, equinoctial; KK ecliptic; HPH, hour circle; *dd*, parallel of declination.

Prolate Spheroid (L. *prolātus*, "prolonged").—A spheroid elongated in the direction of its axis, and distinguished from an *oblate spheroid.* It may be conceived to be generated by the revolution of an ellipse about its major axis.

Proportional Logarithms.—The logarithm of A (a constant quantity), diminished by the logarithm of any other number less than A, is the proportional logarithm of that number. The term, however, is often technically restricted to one particular case by the following definition:—The logarithm of the number of minutes in 3^h or 3°, diminished by the logarithm of the number of minutes in any period less than 3^h or angle less than 3°, is called the proportional logarithm of that period or angle. Proportional logarithms are used in interpolating a lunar distance in the tables given in the "Nautical Almanac".—See under **Logarithms.**

In the definitions given in Article **Logarithms, Proportional,** it will be observed that *numbers* are only dealt with, but as both angles and dates are involved, some further elucidation may be desirable. The question may be considered as follows:

As x and c are in angle, and A and a in date, let B be a standard to which x and c are referred; then from the equation—

$$\log. x = \log. a + \log. c - \log. A$$

by changing signs and adding log. B to each side, we get,

$$\log. B - \log. x = \log. A - \log. a + \log. B - \log. c.$$

1. For sun; $A = 24^h$, let $B = 3^\circ$; then—

$$(\log. 3^\circ - \log. x) = (\log. 24^h - \log. a) + (\log. 3^\circ - \log. c),$$

or, $$\text{prop. log. } x = \text{G.D. log. sun} + \text{prop. log. } c.$$

2. For moon: $A = 12^h$, let $B = 3^\circ$; then—

$$(\log. 3^\circ - \log. x) = (\log. 12^h - \log. a) + (\log. 3^\circ - \log. c),$$

or, $$\text{prop. log. } x = \text{G . D . log. moon} + \text{prop. log. } c.$$

3. For prop. logs.; $A = 3^h$, let $B = 3^\circ$; then—

$$(\log. 3^\circ - \log. x) = (\log. 3^h - \log. a) + (\log. 3^\circ - \log. c),$$

or, $$\text{prop. log. } x = \text{prop. log. } a + \text{prop. log. } c.$$

As 3^h and 3° contain the same number of seconds, the same Table serves for both. The above also shows how it is that the Tables "G . D . log. for sun" and "G . D . log for moon", are used in connection with the Table of "proportional logarithms". This is a point which frequently presents some difficulty to students.

Proportional Parts.—In logarithmic tables, small auxiliary tables are annexed called "Tables of Proportional Parts", the use of which is to facilitate the process of interpolation, thus enabling us to extend the range of our table of logarithms. Their construction depends upon the following principle:—The difference between the logarithms of two numbers not differing much from each other is proportional to the difference of the numbers, or

$$\frac{\log._{10}(N+n) - \log._{10}N}{\log._{10}(N+10) - \log._{10}N} = \frac{n}{10}$$

The tables of proportional parts are therefore simply the results of the expression

$$\frac{n}{10}\left\{\log._{10}(N+10) - \log._{10}N\right\}$$

reduced to numbers for each value of n from 1 to 9. Example:—Our table of logarithms is calculated for 4 figures, but we want the logarithm of a number of 5 figures, 23453. Now, this lies between 23450 and 23460, which differ by 10. The difference of the mantissæ of these numbers, which are the same as those of 2345 and 2346 (viz. 370143 and 370328) is 185. The difference of the mantissa of 23450 and that of 23453 will be found from the proportion

$$10 : 3 :: 185 : x, \therefore x = \frac{3}{10} 185 = 56$$

Hence the mantissa of 23453 is 370199. The process may be continued and the mantissa of a number consisting of 6 figures, and so on, found. The tables of proportional parts are used also in the converse problem, and the number corresponding to a mantissa lying between two tabulated ones may be determined.

Q.

q.—Of the letters used to register the state of the weather in the log-book, q indicates "*Squally*".

Quadrant (L. *quadrans*, "the fourth part").—The fourth part of the circumference of a circle. It contains 90°, and subtends a right angle at the centre.

Quadrant.—An astronomical instrument, the arc of which is 90°, and which is used for measuring angular distances. The form of the instrument has varied through successive improvements, the principal advances from the *Simple Quadrant* being *Davis' Quadrant* and *Hadley's Quadrant*.

The word is now improperly applied to a rough reflecting sector, the arc of which is only 45°.—See **Octant**, **Sector**.

Quadrature (L. *quadratum*, "a quartering").—The moon is said to be in *quadrature* when at one of the two points of her orbit equally distant from *conjunction* and *opposition*, when her position is 90° from the sun.—See **Moon's Phases.**

Quicksilver Horizon.—Quicksilver is the substance best adapted to form an artificial horizon. As a fluid, its surface assumes at rest a horizontal position, and this surface has the brightness of a burnished silver mirror.—See **Artificial Horizon.**

R.

r.—Of the letters used to register the state of the weather in the log-book, r indicates "*Rain—i.e. Continuous Rain*".

Race (D. *ras;* Sw. *resa*).—When the tide-wave, while advancing along the shore, is arrested by a promontory, the water, under certain conditions, attains a height which causes it to flow off obliquely with considerable velocity; such a current is called a "Race." Example—the Race of Portland. The word is doubtless of Scandinavian origin, the inhabitants of the Orkney Islands calling these currents *roosts.*

Radius of Curvature.—The radius of the curvature.—See **Curvature.**

Radius Vector (L. *vector*, "one that carries").—The radius which, revolving round a fixed centre or *pole*, from an initial position, defines the place of any point in space. The length of the radius vector between the pole and the point is one of the polar co-ordinates of the point.—See **Co-ordinates.**

Rate of Chronometer.—The daily change in its error; designated *gaining* when the instrument is going too fast, and *losing* when it is going too slow.—See under **Chronometer.**

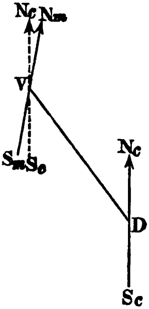
Rating the Chronometer.—Determining its rate.—See under **Chronometer.**

Rate of Sailing.—This is found by "heaving the log", as a rule, every hour; but it must be borne in mind that the result which this gives may be very far from the truth for the whole hour. The rate varies with the strength and direction of the wind, the quantity of sail set, the trim of the sails, the running of the sea, and the skill of the helmsman. Experience and practice are requisite for truly estimating the rate. Various plans have been proposed for obtaining the rate; but the ordinary log, thrown every hour, and the patent log, towed overboard for a continuous period, are those universally adopted.—See **Log.**

Rational Horizon (L. *rationalis*, from *ratio*, "reason", a "reckoning"). —A plane passing through the earth's centre, parallel to the tangent-plane at the observer's station. It is distinguished from this plane, which is called the *sensible* horizon. As the zone they include is of evanescent breadth compared with the indefinite distance of the celestial concave, they coincidently cut it in the same great circle—the *celestial horizon*.—See **Horizon.**

Reaumur's Thermometer.—A thermometer, named after its inventor, in which the distance between the freezing and boiling point of water is divided into 80°, the former being marked 0°.—See **Thermometer.**

Reciprocal Bearings.—The bearings of two stations from each other taken simultaneously. They are used in one of the methods for determining the deviation of the standard compass. Some students appear to have a difficulty in determining whether the deviation deducted is easterly or westerly. The following mode of treatment will remove all uncertainty. Let D and V be the positions of the ship and shore compasses; the line joining these is fixed. From this initial line lay off the two angles at D and V; this will give the directions of the two needles. Through V draw a line parallel to the needle at D; if this lies to the right of the needle at V the deviation is easterly, if to the left it is westerly. Example—the shore compass bears from the ship N. 38° W., and the ship compass bears from the shore S. 46° E. At D the needle lies 38° to the east of the fixed line DV, and gives N_cDS_c the direction of the needle affected by deviation. Again, at V the needle lies 46° to the west of the fixed line VD, and gives N_mVS_m the direction of the needle unaffected by deviation. Through V draw N_cVS_c parallel to N_cDS_c. It will now be seen at once that the compass north, being drawn to the west of the magnetic north, the deviation of the compass is westerly.



Reckoning (A.-Sax. *recan*, Ger. *rechnen*).—The process of finding the position of a ship by observations and calculations. She is said to be *out of her reckoning* when the position so determined turns out to be different from the true place. *Dead reckoning* describes the method where the data used are derived only from the use of the log and compass.

Reduced Latitude.—The "*central*," "*geocentric*," or "*latitude on the sphere*" is so called. Except at the poles and the equator it is always less than the *normal*, *true*, or *latitude on the spheroid*, and the correction for finding it from the latter (which is that deduced from observation) is subtractive; hence the name. The reduced latitude is the angle which the line joining the station of the observer with the centre of the earth makes with the plane of the equator.—See under **Latitude.**

Reduced Zenith.—The point in which the line joining the centre of the earth and the observer's station produced into space meets the celestial concave. Except at the equator and the poles, the reduced is lower in position than the *true zenith;* hence the name.—See **Zenith.**

Reduction.—The process of applying the corrections to the apparent place of a heavenly body to obtain its true place. These corrections are five in number. (1) *Refraction* allows for the bending of the visual rays from a straight course in the passage through the atmosphere, and does away with the disturbance of this medium; (2) *Parallax* places the observer virtually at the centre of the earth instead of on its surface; (3) *Aberration* gives what the observation would have been from a motionless instead of a moving station; (4) and (5) *Precession* and *Nutation* refer the place of the body to fixed and determinate instead of constantly varying celestial circles.

Reduction of the Latitude, or "*Angle of the Vertical*".—The correction by which the latitude on the spheroid (that found from observations) is reduced to the latitude on the sphere, which is that which is often required in the solution of problems.—See under **Latitude.**

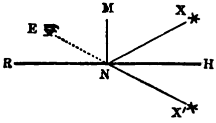
Reduction to the Meridian.—The latitude of a place is most simply determined by the observation of the meridian altitude of a known heavenly body. When such an observation cannot be obtained by reason of the state of the weather, the altitude of the body may often be obtained a little before or a little after its meridian passage. And if at the time of observing such an altitude near the meridian the hour-angle of the body is obtained, we may find by computation very nearly the difference of altitude by which to reduce the observed to the meridian altitude. The correction is called the "Reduction to the Meridian". In point of simplicity, this method of finding the latitude is next to that by the actual observation of the meridian altitude. Even when the meridian altitude can be observed, it will be liable to errors of observation, and may be too great or too small. A reduction to the meridian which will enable us to make use of a larger number of observations will obviously diminish the probable error of each.—See under **Latitude** (II.).

Reflecting Circle.—An astronomical instrument for measuring angular distances; it is the same in principle with the sextant, but its limb is a complete circle.—See under **Circle.**

Reflecting Sector.—The general name for all instruments similar in principle to Hadley's Quadrant, whatever be the extent of their limb.

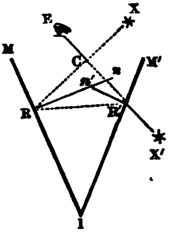
Reflection (L. *reflectĕre*, "to turn back").—A turning back after striking upon any surface, applied to light, heat, sound, etc. We are concerned only with light. When a ray of light is incident upon a plane polished surface, the angle which its direction makes with the normal (or perpendicular) to the surface is called the *angle of incidence*, and the angle which its direction, after being turned back from the surface, makes with the normal is called the *angle of reflection.* The experimental laws of reflection are—(1) The incident and reflected rays lie in the same plane with the normal at the point of incidence, and on opposite sides of it; (2) The angles of incidence and reflection are equal. Two most important practical deductions from these laws are the following:—

1. *Principle of the Artificial Horizon.*—The image of an object reflected from a horizontal surface appears as much below the horizontal line as the object itself is above it; and hence the angular distance between the object itself and the reflected image gives double the altitude of the object. For the angle of incidence (XNM) being equal to the angle of reflection (MNE), $\angle$ HNX = $\angle$RNE = $\angle$HNX′ (Euc. i. 15) $\therefore$ $\angle$XNX′ = 2HNX.



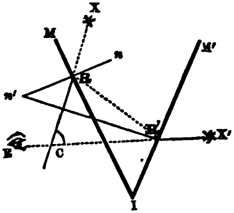
2. *Principle of Hadley's Sextant, and similar instruments.*—The deviation of a ray of light which is reflected at the surface of two plane mirrors, inclined to each other at a given angle, in the plane perpendicular to the

line of their intersection, is double the angle between the mirrors. Let IM, IM′ be sections of the two mirrors by the plane in which the course of the ray XRR′E lies, and let XR and R′E intersect each other in C. To an eye at E the image of the source of light X will appear in the direction ER′, the ray having been deflected through the angle XCR′. To find this angle. There are two cases, according as the normals R*n*, R′*n*′ intersect (in the point *n*′) between the mirrors or not.



Case 1.

$$\begin{aligned} XCR' &= CRR' + CR'R \\ &= 2\,(nRR' + n'R'R) \\ &= 2\,(\pi - Rn'R') \\ &= 2\,I \text{ (Euc. i. 32, cor. 1).} \end{aligned}$$



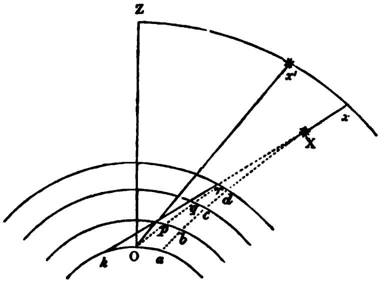
Case 2.

$$\begin{aligned} XCR' &= XRR' - RR'C \\ &= 2nRR' - 2\,n'R'C \\ &= 2\left(\frac{\pi}{2} - R'RI\right) - 2\left(\frac{\pi}{2} - RR'M'\right) \\ &= 2\,(RR'M' - R'RI) \\ &= 2\,I. \end{aligned}$$

It is thus that the sextant, with a limb of 60° only, can be used to measure an angle of 120°. The divisions on the limb are made half their natural extent, so that the reading-off gives at once the angle observed.

Refraction (L. *refractus*, from *refringĕre*, "to break").—When a ray of light passes from one medium to another (a *medium* being whatever allows the transmission of light), its direction is broken and changed at the surface which separates the two; this change of direction is called refraction. The following are the experimental laws of refraction; (1) The incident and refracted rays lie in the same plane with the normal (or perpendicular) to the surface at the point of incidence, and on opposite sides of it; (2) The sine of the angle of incidence bears to the sine of the angle of refraction a ratio dependent only on the nature of the media between which the refraction takes place, and on the nature of the light. The subject of refraction is of great importance to the navigator, as being the principle on which the telescopes used by him are constructed, and as affecting the observations made by him.

Refraction, Astronomical.—The deflection caused in a ray of light from a heavenly body by its passing through the earth's atmosphere; and (as an object always appears in the direction the visual ray has when it enters the eye) the consequent alteration in the apparent place of the body as seen by a spectator on the earth's surface. The term *Refraction* is also used in a technical sense for the correction to be applied to the place of a heavenly body, as actually viewed through the atmosphere, to reduce it to what it would have been had the body been viewed through a uniform medium. The general effect of refraction is to cause the heavenly bodies to appear higher above the horizon than they actually are. Let O be the station of the observer on the earth's surface, OZ the normal to the surface at O, Z the true zenith. The atmosphere may be conceived as formed of concentric strata of air, diminishing in density as they recede from the earth's surface. Let X be a heavenly body beyond the limit of the atmosphere. Then, if there were no atmosphere, X would be referred to *x* on the celestial concave by means of a ray of light proceeding in the straight line XO; but



the intervention of the atmosphere causes this ray to be so refracted that it never reaches the eye of the observer at O at all, for on entering each stratum it is bent towards the normal (and more so as these strata increase in density), and finally reaches the earth's surface at a. The observer at O actually sees the body X by a ray which, if there were no atmosphere, would strike the earth's surface behind him at k, but which, by the intervention of the atmosphere, is refracted in the direction rqpO. In the limit, when we consider the strata to be indefinitely thin, the path of the ray through the atmosphere will be a continuous curve, and the direction in which the object will be seen will be the tangent to the curve at the point nearest to the observer's eye. As the atmosphere is similar on opposite sides of the vertical plane through ZOX, the rays of light from X will not be refracted out of that plane; hence a heavenly body appears to be raised by refraction in a vertical plane above its true place. The body X will thus be referred by the observer at O to the point x' of the celestial concave. The arc xx' is therefore the alteration in the apparent place of the body X due to refraction, and this quantity has to be applied as a correction to the apparent place in finding the true. As refraction, like parallax, takes place in a vertical plane, these two corrections, though altogether different in their character, are combined, and form the "Correction in Altitude".

Refraction is of all astronomical corrections the most difficult to determine with accuracy. The refracting power of the atmosphere varies with its density, and this is affected in any particular stratum, not only by the superincumbent *pressure*, but also by its *temperature* and its degree of *moisture;* and we are not definitely acquainted with the laws of their distribution. The following are the general features of astronomical refraction:—

1. It takes place in a vertical plane. In the zenith there is no refraction; in descending from the zenith to the horizon it continually increases; the rate of its increase, especially near the zenith, is nearly in proportion to the tangent of the apparent zenith distance; the law, however, near the

horizon becoming more complicated. The average amount of refraction for an object at the apparent altitude of 45° is about 1′ (more accurately 57″); at the visible horizon it amounts to 33′, which is rather more than the greatest apparent diameter of the sun or moon. We must here note some resulting phenomena.

(*a*) When the bodies are near the horizon the effect of refraction will be different in degree for different points of so considerable a disc as that of the sun or moon. The highest and lowest points of the vertical diameter will both be raised by refraction, but the lowest more than the highest; consequently the diameter will be shortened, and the same thing will be true for every line parallel to this diameter. The horizontal diameter will not appreciably be altered. There will in reality be a slight, though a very slight, alteration, as the two extremities of the diameter will be raised in vertical arcs which meet in the zenith. From the above it appears that when observations of the sun or moon are taken near the horizon, a correction must be made to the semidiameter before applying it.

(*b*) Since the refraction near the horizon amounts to 33′, the sun will appear just above the horizon when he is in reality entirely below it; and hence refraction has a considerable effect, especially in high latitudes, in lengthening the period of daylight. It has a similar effect in the time of the rising and setting of the other heavenly bodies.

(*c*) Hence also the great refraction at the horizon sensibly affects the apparent amplitude, and a correction for refraction thus becomes necessary in obtaining correctly the true amplitude of a body.

2. When the barometer is higher than its mean height, the amount of refraction is greater than its mean amount; when lower, less. The colder the air, the greater the refraction. The Tables of Refraction in use among navigators are constructed on the supposition that at the level of the sea the barometer stands at 30 inches, and Fahrenheit's thermometer at 50°, according to Ivory. The argument of the principal table which

gives this mean value, is the apparent altitude; the corrections for the height of the barometer and thermometer being given in auxiliary tables.

Refraction, Terrestrial.—The change in the position of terrestrial objects due to their being viewed through the medium of the atmosphere. In astronomical refraction the object is without the limits of the atmosphere; in terrestrial refraction the object is within the atmosphere. The effect is in general to make an object appear higher than its true place, and its average amount is about $\frac{1}{14}$ of the intercepted arc. As a minute of a degree of a great circle of the earth is in length nearly a mile, the refraction in minutes may be thus obtained from the distance in miles. The amount, however, of terrestrial refraction is subject to great irregularity, and varies between $\frac{1}{3}$ and $\frac{1}{23}$ of the intercepted arc. The most important object to the navigator which is thus affected is the sea-horizon. In consequence of refraction, the apparent dip is less than the true.—See under **Depression.**

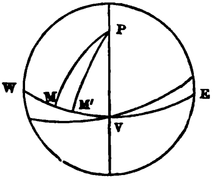
Regulus (L. diminutive of *rex*, "a king").—The name of the bright star *α Leonis*. The word is a translation of the old Greek name for the star *βασιλίσκος*, "the little king".—See **Leo.**

Repeating Circle.—An astronomical circle constructed on the principle of repeating the measurement of the angle required without multiplying the single reading-off, thus theoretically diminishing by division, to any degree, the error arising from imperfect graduation.—See under **Circle.**

Retard or **Age of the Tide.**—The interval between the transit of the moon at which a tide originates and the appearance of the tide itself.—See under **Tide.**

Retardation (L. *retardatio*, "a slowing" from *tardus* "slow"). A relative decrease in velocity, opposed to *acceleration;* it may be regarded as acceleration reckoned negatively.—See **Acceleration.**

Retardation of Mean Solar on Sidereal Time.—The change of the mean sun's right ascension in a sidereal day, in consequence of which he appears to hang back, as it were, in his diurnal revolution. Hence the name. To explain this—Let V be the first point of Aries on the meridian on any particular day, and VPM the corresponding mean solar time. When the first point of Aries comes again to the meridian after the lapse of a sidereal day, the mean sun will have moved to the east by reason of his proper motion in right ascension, through the arc MM′ say. Thus in the diurnal revolution from east to west the mean sun will be at M′ instead of at M, appearing therefore to hang back, and the mean solar time to be "retarded" with reference to sidereal time. The amount of retardation for any given interval of sidereal time will enable us to deduce the mean solar time. In the "Nautical Almanac", pp. 480, 481, is given a "Table for converting Intervals of Sidereal Time into Equivalent Intervals of Mean Solar Time".—See **Acceleration of Sidereal on Mean Solar Time.**



Retrograde Motion.—The gradual advance of the planets in the heavens is from east to west. This is called the *direct* motion, and predominates, though broken by periods of *station* and motion from east to west. This latter is called *retrograde* motion.

Revolving Storms.—The name commonly given to those violent storms which, while advancing bodily in a definite direction, rotate about an axis with great rapidity. A more correct and appropriate generic term would be *Spiral Storms.* They are experienced at certain periods of the year in low latitudes, and are called, in different parts of the world, *Cyclones*, *Hurricanes*, *Typhoons*, and *Tornadoes.*—See **Storms.**

Revolution and Rotation.—See **Rotation.**

Rhumb Line (Gk. ῥόμβος, "a whirl" from ῥέμβειν, "to turn round and round").—The curve on the earth's surface which cuts all the meridians at the same angle. The word rhumb was formerly applied to the points of the compass, and hence "to sail on a rhumb" was to sail on a particular compass direction; hence again the term came to be applied to the track described by a moving body which always keeps a constant course. As the meridians all converge to the pole, any rhumb curve if continued will wind round the globe and approximate to the pole without, however, ever reaching it; it is hence called the *Equiangular spiral* and the *loxodromic curve.* That such a curve may be drawn through any two given points will appear from this consideration—that from one of the points an indefinite number of these curves can be drawn making different angles with the meridian, and on some one of these the second point must lie. It is evident, also, that only one of these curves can pass through the two points. The rhumb is the track used ordinarily in navigation, for although it has the disadvantage of not being the shortest distance between two places, it possesses the advantages of not requiring the navigator to alter his course, and of being represented by a straight line on the Mercator's chart. This straight line, however, it must be borne in mind, only marks the course, equal parts of it not representing equal distances on the earth.

Rhumb Sailing.—In rhumb sailing the ship keeps on the rhumb curve passing through the place of departure and the place of destination. This is the ordinary sailing used in navigation, for when out of sight of land the compass determines the navigator's track, and hence the selection of that track which makes a constant angle with the meridian. When in sight of his port the compass is no longer needed, and the navigator gives up rhumb sailing, and makes for the harbour on a great circle. Strictly speaking, when accurately following a compass-course we are only approximating, though very closely approximating, to a rhumb line, on account of the continuous alteration in the variation due to the magnetic pole and the pole of the earth not being coincident. This change in the variation is taken into account in shaping the course every day. The calculations in rhumb sailing are exceedingly simple. All problems not involving difference of longitude may be determined by the solution of a right-angled plane triangle, or simply by the use of a table called the "Traverse Table"; those involving difference of longitude are worked out by the aid of a second table called the "Table of Meridional Parts". Mercator's chart is the one used in this sailing, on it the rhumb appearing as a straight line.—See **Sailings.**

Rhumb Sailing: The Fundamental Definitions.—The six fundamental definitions of Rhumb Sailing may be thus grouped—(1) *The Course* and *The Distance;* (2) *The Difference of Longitude* and *The True Difference of Latitude;* (3) *The Departure* and *The Meridional Difference of Latitude.* These will be found defined under their several heads, but they may be conveniently explained together with the aid of the adjoined figures. Fig. 1 is a stereographic projection on the first meridian, fig. 2 a stereographic projection on the equator, and fig. 3 Mercator's projection. Let PP′ be the poles of the earth, QqQ′ the equator, PQP′ the first meridian; and let ZZ′ be two places on the surface, PZq and PZ′q' their meridians, cutting the equator in q and q'. Then

1. *Course* and *Distance.*

Let the rhumb line ZZ′ be drawn between Z and Z′. The characteristic property of this curve is that it cuts all the intermediate meridians, Pr_1q_1, Pr_2q_2, Pr_3q_3, ... at the same angle, *i.e.* it makes the angle $PZZ' = Pr_1Z' = Pr_2Z' = \ldots\ldots$; the common angle PZZ′ is called the *Course* between Z and Z′; and the arc ZZ′, expressed in nautical miles, is called the *Distance.*

2. *Difference of Longitude* and *True Difference of Latitude.*

Draw the parallels of latitude pZ and p'Z′ through Z and Z′. Then Qq and Qq' are the longitudes respectively of Z and Z′, and Qp, Qp', their latitudes. Then the arc qq' is called the *Difference of Longitude*, and the arc pp' the *True Difference of Latitude*, of Z and Z′. N.B.—It is the *algebraic* difference that is always meant in such cases.

Fig. 1.

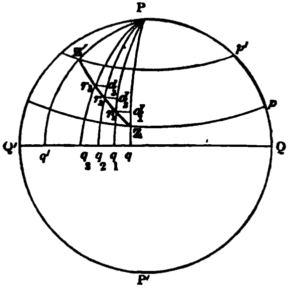
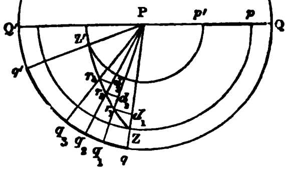


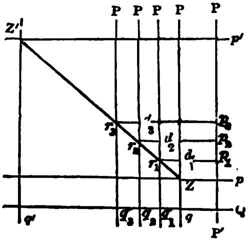
Fig. 2.



3 *Departure* and *Meridional Difference of Latitude.*

On the curve ZZ′ take the points r_1, r_2, r_3, ... indefinitely near to each other, r_1 being indefinitely near to Z, and through them draw the meridians Pq, Pq_1, Pq_2, Pq_3, ... and the arcs of parallels of latitude r_1d_1, r_2d_2, r_3d_3, ... In the limit, the triangles Zr_1d_1, $r_1r_2d_2$, $r_2r_3d_3$, ... in figs. 1 and 2 may be considered right-angled *plane* triangles. Then, the sum of all the arcs d_1r_1, d_2r_2, d_3r_3, ... between Z and Z′ is called the *Departure;* and if these elementary arcs of the departure, d_1r_1, d_2r_2, d_3r_3, ... be supposed to become equal respectively to the corresponding differences of longitude qq_1, q_1q_2, q_2q_3, ... in fig. 3,

Fig. 3.



the triangle Zr_1d_1, $r_1r_2d_2$, $r_2r_3d_3$, ... remaining similar to themselves during the change, then the sum of all the elementary portions of latitude Zd_1, r_1d_2, r_2d_3, ... thus increased is called the ***Meridional Difference of Latitude.***

Rhumb Sailing: Fundamental Propositions.—The three general formulæ which embody the fundamental propositions of rhumb sailing are—

$$1.\ \text{Sin course} = \frac{\text{dep.}}{\text{dist.}}$$

$$2.\ \text{Cos course} = \frac{\text{true diff. lat.}}{\text{dist.}}$$

$$3.\ \text{Tan course} = \frac{\text{diff. long.}}{\text{mer. diff. lat.}}$$

In the particular case of "parallel sailing" the formula used is

$$4.\ \text{Dist.} = \text{diff. long.} \times \text{cos lat.}$$

from which again the formula for the approximate method of "middle-latitude sailing" is deduced—viz.

$$5.\ \text{Dep. (nearly)} = \text{diff. long.} \times \text{cos mid. lat.}$$

These two latter equations will be found proved under the headings **Parallel Sailing** and **Middle-Latitude Sailing**; the three general ones may be proved together as follows:—Using the figs. 1 and 2 of the last article, and remembering that in the limit the triangles Zd_1r_1, $r_1d_2r_2$, $r_2d_3r_3$, ... are considered right-angled plane triangles; then

$$\begin{aligned} 1.\ d_1r_1 &= Zr_1 \sin d_1Zr_1 \\ d_2r_2 &= r_1r_2 \sin d_2r_1r_2 \\ d_3r_3 &= r_2r_3 \sin d_3r_2r_3 \\ \ldots &= \ldots \end{aligned}$$

$$\therefore d_1r_1 + d_2r_2 + d_3r_3 + \ldots = (Zr_1 + r_1r_2 + r_2r_3 + \ldots) \sin PZZ'$$

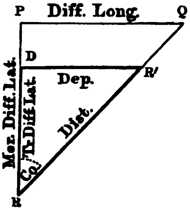
$$\text{or Departure} = \text{distance} \times \text{sin course.}$$

$$
\begin{aligned}
2.\quad Zd_1 &= Zr_1 \cos d_1Zr_1 \\
r_1d_2 &= r_1r_2 \cos d_2r_1r_2 \\
r_2d_3 &= r_2r_3 \cos d_3r_2r_3 \\
\ldots &= \ldots \\
\therefore Zd_1 + r_1d_2 + r_2d_3 + \ldots &= (Zr_1 + r_1r_2 + r_2r_3 + \ldots) \cos PZZ'
\end{aligned}
$$

or True difference latitude = distance × cos course.

$$
\begin{aligned}
3.\quad d_1r_1 &= Zd_1 \tan d_1Zr_1 \\
d_2r_2 &= r_1d_2 \tan d_2r_1r_2 \\
d_3r_3 &= r_2d_3 \tan d_3r_2r_3 \\
\ldots &= \ldots \\
\therefore d_1r_1 + d_2r_2 + d_3r_3 + \ldots &= (Zd_1 + r_1d_2 + r_2d_3 + \ldots) \tan PZZ' \\
\text{Tan } PZZ' &= \frac{d_1r_1 + d_2r_2 + d_3r_3 + \ldots.}{Zd_1 + r_1d_2 + r_2d_3 + \ldots.} \\
&= \frac{qq_1 + q_1q_2 + q_2q_3 + \ldots.}{pp_1 + p_1p_2 + p_2p_3 + \ldots.} \text{ (fig. 3)}
\end{aligned}
$$

$$\text{or Tan course} = \frac{\text{difference of longitude.}}{\text{meridional difference of latitude.}}$$



The above important formulæ may be easily remembered by carrying in the mind's eye the adjoining figure of two similar plane triangles. The smaller one RDR' is first drawn similar to one of the spherical triangles, *rdr*, in its evanescent condition, and then the larger one RPQ is completed, so that

$$\frac{RP}{RD} = \frac{\text{Mer. Diff. Lat.}}{\text{True Diff. Lat.}}$$

$$\text{and therefore } \frac{PQ}{DR'} = \frac{\text{Diff. Long.}}{\text{Dep.}}$$

We must caution students against assuming this as a proof of the formulæ.

Rigel.—The Arabic name for the bright star β *Orionis.*—See **Orion.**

Right Ascension (L. *rectus*, "right", "straight"; *ascensio*, "rising").—The right ascension of a heavenly body is the arc of the equinoctial intercepted between the first point of Aries and the circle of declination passing through the place of the body. Or it may be defined as the angle at the pole of the heavens, between the hour-circle passing through the first point of Aries and that passing through the place of the body. Right ascension is always reckoned from the first point of Aries eastward (in conformity with the direct motions of the heavenly bodies). It is estimated either in *time*, by hours, minutes, and seconds, from 0 to $24^h\ 0^m\ 0^s$, or in angular magnitude, by degrees, minutes, and seconds, from 0 to 360° 0′ 0″. Right ascension and declination are the equinoctial co-ordinates for defining the positions of points on the celestial concave, and indicating their positions relatively to each other. To understand the derivation of the term, it must be borne in mind that the words "ascension" and "descension" were formerly used with reference to the rising and setting of the heavenly bodies. The *ascension* was the arc of the equinoctial intercepted between the first point of Aries and the east point when the body is rising; the *descension* the arc of the equinoctial intercepted between the first point of Aries and the west point when the body is setting. We follow further the former term only. On the oblique sphere the ascension was qualified as the "oblique ascension" to an observer anywhere but on the equator or at the poles, the heavenly bodies shooting up obliquely from the horizon. On the right sphere the word was qualified as the "right ascension" to an observer at the equator, the heavenly bodies shooting up perpendicularly from the horizon. Thus, if X be a body rising, E the east point, and ♈ the first point of Aries, then (fig. 1) ♈ E is the oblique ascension of X. Again (fig. 2) where R is the east point, ♈ R is the right ascension of X. The oblique and right ascension are connected thus:—Draw (fig. 1) the hour-circle PX, intersecting the equinoctial in D; then the right ascension ♈ R is found by taking from the oblique ascension ♈ E the arc RE, which is called the "ascensional difference", its magnitude depending upon the latitude of the observer.

Fig. 1.

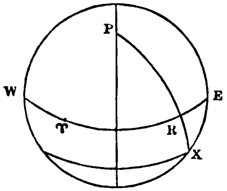
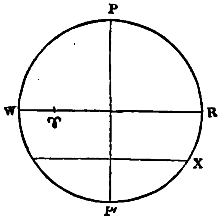


Fig. 2.



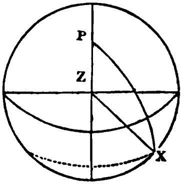
Right Ascension, Circles of.—Great circles of the celestial concave passing through the poles of the equinoctial, and so called because they severally mark out all points that have the same "right ascension". In the polar system of equinoctial co-ordinates, used for indicating the places of celestial objects relatively to the position of the observer on the earth's surface, these circles are named "*Hour Circles*", as marking out all the points that have the same hour-angle. They are generally called "*Circles of Declination*", after the analogy of rectilinear co-ordinates, from the element that is measured, not *by* them, but *upon* them—the declination.—Compare "Circles of Longitude"; "Circles of Azimuth".

Right Ascension and Declination.—The equinoctial co-ordinates for defining the position of points of the celestial concave, and indicating their positions relatively to each other. Right ascension is measured on the equinoctial from the first point of Aries eastward (in conformity with the direct movements of the heavenly bodies) from 0 to 24^h; declination is measured on the secondaries of the equinoctial (which are hence called circles of declination) to the north and south poles of the heavens, from 0° to 90°.

Right Sphere.—The sphere in that position in which the circles apparently described by the heavenly bodies in their diurnal revolution are at right angles to the horizon. This is the appearance to a spectator on the equator. The *right sphere* is distinguished from the *parallel sphere* and the *oblique sphere.*

Rising and Setting.—A heavenly body is said to be on the point of *Rising* when its centre is in the eastern part of the celestial horizon; and on the point of *Setting* when its centre is in the western part of the celestial horizon.

To find the time of the rising and setting of a heavenly body. Let c and l be the co-latitude and latitude of the observer, p and δ the polar distance and declination of the body X, and H its hour-angle at rising or setting. Then in the quadrantal triangle PZX



$$\text{Sin } (6^h - H) = - \tan (90° - c) \tan (90° - p)$$
$$\text{Cos } H = \tan l \tan \delta.$$

If the latitude and declination have like names, H will be greater than 6^h, if unlike, it will be less. The figure is for the case where the names are unlike. Let T be the time of the meridian passage of X, t the time of rising, and t' the time of setting. Then

$$t = T - H, \text{ and } t' = T + H.$$

The time of the *apparent* rising and setting differs from the above by reason of the horizon parallax and refraction. The elevation of the spectator again affects the *observed* time of rising and setting.

Rotation (L. *rota*, "a wheel"), and **Revolution** (L. *revolvĕre*, "to roll over again").—These two similar terms, though frequently used indiscriminately, have a slightly different meaning and might with advantage be restricted in their application. We propose to confine the term *rota-*

tion to indicate ***turning round on an axis***, and the term ***revolution*** to indicate ***performing a periodic orbit.***

Run.—*The run of a ship* is the distance sailed. *To run down a coast* is to sail along parallel to it. *To run down a port* was a term describing a method of making the destination in common use before the longitude could be determined as easily and accurately as at present; the ship got into the latitude required and then ran along the parallel, east or west as necessary.

Run, Correction for; or, Reduction of an Altitude to another Place of Observation.—In "double altitudes", taken at different times, the ship may have moved in the interval between the two observations. In this case, therefore, before using the two altitudes in combination, it is, in general, necessary to apply to the first altitude the "Correction for the Run of the Ship", so as to reduce it to what it would have been had it been taken at the place of the second observation, the results of the problem under solution being sought for the later date. In celo-navigation, instead of regarding the place of the ship on the surface of the sea, we consider her zenith, a point of the celestial concave. Let X be the place of the heavenly body at the first observation, Z the zenith of the ship at that time, and Z′ her zenith at the time of the second observation. Then, had the ship's zenith been Z′ at the time of the first observation, the zenith distance of X, instead of being XZ, would have been XZ′. With centre X, radius XZ′ describe an arc cutting XZ (fig. 1), or XZ produced, (fig. 2) in r; then it is evident that Zr is the correction required, as applied to the zenith distance, subtractive when the ship's run has been towards the body, additive when the ship's run has been away from the body; as applied to the altitude, the converse being the case. Now, since the triangle $ZZ'r$ is very small, it may, for practical purposes, be considered a right-angled plane triangle, and

$$Zr = ZZ' \cos Z'Zr.$$

When the run of the ship has been towards the place of the body (fig. 1), the angle Z′Zr is the difference between her course and the true bearing of the body at the first observation; when the run of the ship has been away from the place of the body (fig. 2), the angle Z′Zr is the supplement of this difference.

Fig. 1.

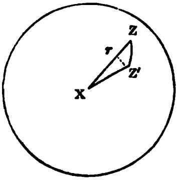
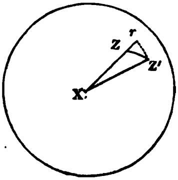


Fig. 2.



This correction may be conveniently found by the aid of the traverse table by entering with the distance run ZZ′ as distance, and the angle Z′Zr as course, the corresponding diff. lat. being the correction required, additive or subtractive as the case may be. If we define the angle between the direction of the ship's run and the bearing of the body at the first observation to be the "angle of run", the two cases are included in the formula

$$\text{Correction for run} = \text{distance run} \times \text{cosine angle of run.}$$

For, when the angle of run is less than 90°, its cosine is positive, and the correction therefore additive to the altitude; and when the angle of run is greater than 90°, its cosine is negative, and the correction is therefore subtractive. If the ship does not preserve the same course in the interval, the course made good must be employed; and as it is the *difference* only of azimuth that enters into this question, the variation (supposed the same at both observations) is not considered; but, if the ship's course changes, the local deviation, when large, should be attended to.

S.

s.—Of the letters used to register the state of the weather in the log-book, **s** indicates "*Snow*".

Sag.—To hang down on one side, to droop. *To sag to leeward* means that a ship is making considerable leeway, not bearing up well to windward or holding a good wind.

Sagittarius, Constellation of (L. "The Archer").—The ninth constellation of the zodiac, lying between Scorpio and Capricornus. It contains no star above the third magnitude.

Sagittarius, Sign of.—The ninth division of the ecliptic, including from 240° to 270° of longitude. Owing to the precession of the equinoxes, the *constellation* Sagittarius no longer occupies the *sign* of this name, the constellation Scorpio having taken its place. The sun is in Sagittarius from about November 23rd to about December 22nd. Symbol ♐.

Sailing Directions.—Books containing local information respecting various seas and coasts useful for the purpose of navigation. The chief topics are, an account of the winds, currents, tides, with directions how to take advantage of these in making certain passages; notices of dangers, such as rocks and shoals, with directions how to avoid them; descriptions of anchorages and ports, with the appearance and bearings of landmarks for making them; the particulars respecting the lighthouses on the coast; memoranda of watering-places, etc. Extracts from different voyages and travels are inserted, conveying, in addition, much useful information respecting the physical aspect of the shores, climate, and natural phenomena, the manners and customs of the inhabitants, the productions and articles of merchandise.

Sailings.—Navigation is divided into *geo-navigation* and *celo-navigation*, with reference to the sources whence the data are derived for finding a ship's present position, and for conducting her on a determined course to another place. With reference also to the instrumental means used for obtaining these data, we distinguish between *dead reckoning* (including "bearings", "soundings", "loggings") and *observation.* But there is nothing in either of these distinctions which has reference to the *track* a navigator adopts in sailing from one place to another. The determination of this track, the representation of it on a chart, and the solution of the problems respecting it, are treated of under the term "sailings". The two tracks the navigator has the choice of are the rhumb and the great circle, and according to which of these he adopts his sailing is called *Rhumb Sailing* or *Great-Circle Sailing.* Again, he may consider the earth an extended plane, or a spherical surface, and exhibit his track on a plane chart or a projected chart; this gave rise to the old distinction of *Plane Sailing*, and *Globular or Spherical Sailing.*

(I.) In Rhumb Sailing the two general problems of navigation are— 1st, Given the latitudes and longitudes of two places, required the course and distance from one to the other; and 2nd, Given the latitude and longitude of a place, and the course and distance from this to another place, required the latitude and longitude of the latter. For the solution of these problems four quantities are involved—the course, distance, difference of latitude, and difference of longitude. If the principles of plane sailing be applied for the solution of these problems, sufficiently correct results can only be obtained in the particular case where the track lies near the equator; but generally these problems may be *partially* solved on the principles of plane sailing. Another quantity is introduced, called the departure, which, like the difference of latitude, bears a constant ratio to the distance, and which is connected with the difference of longitude by a property of the sphere. For the relations of the course, distance, difference of latitude and departure, the principles of plane sailing are sufficient; the principles of spherical sailing being called into requisition only when the difference of longitude is involved. Hence the present adaptation of the terms *plane sailing* and *spherical sailing*, the former treating of the relations of course, distance, difference of latitude and departure; the latter completing the solution of problems by the convertibility and determination of the difference of longitude. The terms have reference to the manner and degree of *solution;* plane sailing requiring the application of plane trigonometry, spherical sailing involving the aid of spherical trigonometry, either in actual computation or in the construction of the tables used. In this sense, under the head of

(i.) Plane Sailing are treated the following:—

1. *Traverse Sailing*, where the object is to obtain the resultant of several successive tracks;
2. *Current Sailing*, where the object is to obtain the resultant of two simultaneous tracks;
3. *Oblique Sailing* is a term applied to those cases for the determination of which an oblique triangle has to be solved.

(ii.) Spherical sailing completes the solution of the problems, and in this there are two methods—

1. *Middle-Latitude Sailing*, which is an approximate method deduced from the particular case of *Parallel Sailing;* and
2. *Mercator Sailing*, which gives accurate results.

The middle-latitude method may be used when the distance run is not great or for greater distances when the difference of latitude is small.

(II.) Great-Circle Sailing cannot absolutely be adopted in practice except in the two cases in which it coincides with rhumb sailing—viz. when the great circle is the equator or a meridian (*Meridian Sailing*);

1. Hence arises what is called *Approximate Great-Circle Sailing*;
2. Again, the practical usefulness of this is often most apparent when it is combined with particular cases of rhumb sailing; hence arises what is called *Composite Sailing*;
3. Even when the great circle, or an approximation to it, is not adopted wholly or in part as the actual track, the consideration of its position often modifies the navigator's sailing. This is the

case in *Windward Sailing*, in which the inquiry is limited to the most advantageous time for tacking.

Satellites (L. *satelles*, "an attendant").—Subordinate bodies which revolve about some of the planets, attending upon them in their revolutions about the sun. The two groups are sometimes distinguished as "*Primary Planets*" and "*Secondary Planets*". Satellites generally are also called "*Moons*", though this is the proper name of the satellite of our globe. They are bodies of the same nature as the planets themselves, and their motions are governed by the same general laws. The earth has one satellite; Mars two; Jupiter four; Saturn eight; Uranus from four to eight; and Neptune certainly one, and probably two or more. Of these the most important to us are the Moon and Jupiter's satellites.

Saturn (named after the mythical father of Jupiter, etc.)—The planet revolving next in order to Jupiter, being about 9½ times the earth's distance from the sun; its actual diameter is about 10 times that of the earth. Besides being attended by eight distinct satellites, it has the curious appendage of a series of broad, flat, rings which encircle its equatorial regions, and are probably composed of an innumerable number of small satellites: the inner one is at an interval of about half the radius of the planet. The apparent diameter of Saturn, at its mean distance from the earth, is about 18″; and it is a very useful body in the problems of celo-navigation. Symbol ♄.

Scorpio, Constellation of (Gk. *σκορπιών*; L. *scorpio*, "The Scorpion").—The eighth constellation of the zodiac, lying between Libra and Sagittarius. When *Scorpio* rises *Orion* sets; a phenomenon embodied in the myth that Orion perished by the sting of a scorpion. The principal star, *α Scorpii* (called also *Antares*), may be found by joining *Spica* with the *South Balance* (*α Libræ*), and continuing the line to about the same distance. *α Scorpii*, mag. 1.2; 1882, R.A. 16^{h} 22^{m}, Dec. – 26° 10′. β^{1} *Scorpii*. mag, 2; 1882, R.A. 15^{h} 59^{m}, Dec. – 19° 29′.

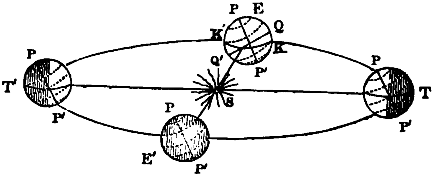
Scorpio, Sign of.—The eighth division of the ecliptic, including from 210° to 240° of longitude. Owing to the precession of the equinoxes, the *constellation* Scorpio no longer occupies the *sign* of this name, the constellation Libra having taken its place. The sun is in Scorpio from about October 23rd to about November 22nd. Symbol ♏.

Sea-Breeze.—A breeze setting from the sea towards the land.

Sea-Horizon.—The small circle which bounds the portion of the surface visible to a spectator in the open sea.

Sea, Mean Level of.—The place midway between the levels of high and low water.

Seasons (Fr. *saison*).—The four cardinal divisions of the year—Spring, Summer, Autumn, Winter. Their succession is caused by the axis of the earth's rotation (which always remains parallel to itself) being inclined to the plane of her orbit round the sun. The elliptic form of the earth's orbit (causing her to vary her distance from the sun) has but little effect in producing the variation of temperature which distinguishes the different seasons, the temperature of any part of the earth's surface depending mainly on the exposure to the sun's rays. In our hemisphere the effect of the change of distance, if appreciable, would be to diminish the effect caused by the inclination. Whenever the sun is above the horizon at any place, that place is receiving heat, and when below, it is parting with heat by radiation, the equilibrium of heat throughout the year being preserved. Now, owing to the inclination of the earth's axis to the plane of her orbit, the time the sun remains above



the horizon at any given place varies. To illustrate this: Let S be the sun, ETE′T′ the earth in her orbit in four positions 90° apart—viz. those which she has about March 20th, the time of the vernal equinox; about June 21st, or the summer solstice; about September 23rd, or the autumnal equinox; and about December 22nd, or the winter solstice; PP′ is the axis of the earth, which always remains parallel to itself, directed to the same vanishing point of the heavens. In the position E, at the time of the vernal equinox, the sun appears in the intersection of the equinoctial and the ecliptic, whose planes cut the earth in the circles QQ′ and KK′; and the poles of the earth fall on the great circle which divides the enlightened from the darkened hemisphere. Hence as the earth rotates on her axis every point of her surface describes half its diurnal course in light and half in darkness—*i.e.* the day and night are equal all over the globe. The same holds good for the position E′—viz. at the autumnal equinox. Again, at the position T, at the summer solstice, the north pole, with an encircling zone in breadth equal to the angular distance between the poles of the equinoctial and ecliptic, is situated entirely within the enlightened hemisphere, and as the earth rotates on her axis the whole of this part remains constantly enlightened. Hence at this point of her orbit it is constant day at the north pole and the arctic zone; on the other hand, the south pole, with the antarctic zone, is immersed in darkness during the entire diurnal rotation—*i.e.* it is constant night. Again, in the remaining regions of the earth it is evident that the nearer a place is to the north pole the longer it will remain in the illuminated hemisphere in the diurnal rotation, every station north of the equator having a day of more and a night of less than 12 hours, and *vice versâ* for places south of the equator. All these phenomena are exactly inverted when the earth arrives at the opposite position of her orbit T′, at the winter solstice. Now let us remark the changes as the earth passes from one of these critical positions to the next. As the earth moves from E to T, in the northern hemisphere the days grow longer and the nights shorter, and consequently the temperature of every part of that hemisphere increases, and spring is succeeded by summer; in the southern hemisphere the reverse of this takes place, and the transition is from autumn to winter. Again, as the earth moves from T to E′ the days and nights approach equality, and consequently the excess of temperature above the mean in the northern and the defect below the mean in the southern hemisphere is reduced; and in the former summer subsides into autumn, in the latter winter is replaced by spring. As the earth passes from E′ to T′, and again from T′ to E, the same phenomena will be repeated, but reversed; the transition being in the northern hemisphere from autumn to winter, and from winter to spring, while in the southern it is from spring to summer, and from summer to autumn.

Second Differences.—The differences (corresponding to equal intervals of time) in the successive values of a varying quantity, if the quantity do not vary uniformly, exhibit differences among themselves,—these are called *Second Differences*. Thus, in a series of altitudes observed at equal intervals of time (since the altitude does not vary at the same rate at the beginning, middle, and end of the interval), the differences between them, taken in succession, will generally exhibit second differences. So again with the elements tabulated in the "Nautical Almanac". If these quantities varied uniformly in the interval between the dates for which their values are given, an intermediate value could be correctly interpolated by a simple proportion. The method of "proportional parts" would give the actual change in the interval between the date of one of the tabulated values and that for which we wish to interpolate. But the rate of varying itself varies during the interval, and hence, when great accuracy is required, the necessity for a correction to the change found by proportional parts, which correction is called the "*Equation of Second Differences*". The question of finding the second difference is simply the finding the rate at which the rate of varying varies. This may be done by taking two values of the quantity from the table on each side the required one, and setting them down in order; then add together the 1st and 4th and the 2nd and 3rd, observing which sum is the greater; half the difference of the two sums is the second difference. The equation of second differences is found by the help of a table. This correction is of the most importance when the quantity under consideration attains a maximum between two times given in the table. The greatest error that can arise in any case from neglecting it is $\frac{1}{8}$ of the whole second difference.

Secondary Circles.—Great circles of the sphere passing through the poles of another great circle, which is called their *Primary*.

Secondary Meridians.—Meridians of the earth which are determined like the *first*, *prime*, or *primary* meridians, such as those of Greenwich, Paris, etc., by astronomical or absolute evidence, independently of the chronometrical or relative method. The primary meridians are those from which the longitudes in the tables and on the charts are reckoned; the secondary meridians are useful as fundamental and independent starting-points in making passages.

Sector.—In geometry—A sector of a circle is the figure contained by two straight lines drawn from the centre, and the circumference between them (Euc. iii. def. 10). Sectors of different circles are said to be *similar* when the sides or bounding radii include equal angles.

Sector.—A mathematical instrument, generally found in an ordinary portable case, with the use of which the navigator should be familiar. It is a universal scale by the aid of which every problem in geometrical drawing may be solved; hence it is of great use in laying down plans and in making diagrams. From its application in graphically working questions in proportion, the French call it the *Compass of Proportion*. It consists of two equal rulers called legs, which represent the two radii, movable about the centre of the connecting joint, this centre representing the centre of the circle. By opening the legs any sized sector can be obtained. A full description of this instrument will be found in Heather's book on "Mathematical Instruments", vol. i. p. 42 (Weale's Series).

Sector.—An astronomical instrument for measuring the angular distance between two points.

The word is specially applied to the *Zenith Sector*, a fixed shore instrument constructed for the purpose of determining with great accuracy the meridian zenith distances of stars passing within a few degrees of the zenith.

At sea a portable hand sector is used for taking the altitudes of heavenly bodies above the sea horizon, for finding the distance of heavenly bodies from the moon, and for determining for the bearings and distances of terrestrial objects. Such an instrument is known as a *quadrant* or *sextant*.

It would be a great advantage, as conducing to consistency of usage and to clear ideas on their construction, if the word "sector" were adopted as a generic term to include all such instruments formed by two radii of a circle and the intercepted arc. These instruments are of two kinds:—(I.) When the length of the graduated arc measures the angular distance between the two objects; (II.) When the length of the arc required corresponds to only half the angle between the two objects. The instruments at present used are of the latter kind, those of the former being practically obsolete. There is no confusion in assigning names to the different forms of the first class, but great laxity prevails in speaking of those of the second class.

(I.) 1. There was the old *Common Quadrant*, which was merely a graduated quarter of a circle, having a movable radius whereon were two sights for directing it to the object; there were two other sights on the fixed initial radius, to be directed to the horizon.

2. There was the *Back-Staff* called *Davis's Quadrant*, and by French navigators the *English Quadrant*. This consisted of two arcs, the greater containing 60° or 65° between short radii, and the less containing 30° or

25° between longer radii; the two together making the 90° of the quadrant, hence the correctness of retaining the old name.

(II.) When the principle of the *Reflecting Sector* was invented by Newton and subsequently by Hadley, the old name quadrant continued to be applied by seamen to the instrument whatever was the length of arc with which it was constructed. The term *Hadley's Quadrant* commonly included both the *Octant* and *Sextant;* though these words are strictly applied by the accurate old writer, J. Robertson.

1. The *Octant* has an arc of an eighth of the circumference, and it measures an angle of 90°.

2. The *Sextant* has an arc of a sixth of the circumference, and it measures an angle of 120°.

At the present time what is called the *Quadrant* is simply a rougher kind of reflecting sector; the limb being about 45°, and the instrument able to measure angles up to 90°, the limit of altitudes. From this latter circumstance, it is supposed, though erroneously, to have derived its name; but in fact, it has inherited this from its predecessors. The word is now colloquially used for any common instrument of the kind of wooden framework, whatever be the length of its arc, in consequence of its similarity in appearance to the old-fashioned quadrant.

The term *Sextant* is applied to a more elaborately constructed instrument of exactly the same kind, but of greater extent of arc, and adapted to measure accurately lunar and other angular distances. The form which first came into general use had the arc one-sixth part of the circumference, and this gave the name to subsequent modifications; in the most modern the arc is graduated up to 140 principal divisions, each being equal to half a degree.

It appears from the above, that neither of the two instruments in common use can any longer with correctness continue to bear the name ordinarily applied to them; the quadrant having generally an arc of 45°, and the sextant an arc of 70°. We would suggest the adoption of the word **Sector** as a general term, as both appropriate and accurate to include every variety. Its sound is similar to the word *Sextant*, and this will facilitate its introduction. If it be desired to specify the several varieties, the following terms are available:—

1. The *Octant*, arc of 45°, the eighth of the circle.
2. The *Sextant*, arc of 60°, the sixth of the circle.
3. The *Quintant*, arc of 72°, the fifth of the circle.
4. The *Quadrant*, arc of 90°, the fourth of the circle.

Semi.—The Latin prefix indicating the half. Thus we have *semi*circle, *semi*diameter, *semi*menstrual, *semi*horal, etc. The corresponding Greek prefix is ἡμι-, which we find in *hemi*sphere, *hemi*cycle, etc.

Semidiameter.—The semidiameter of a heavenly body is half the angle subtended by the diameter of the visible disc at the eye of the observer. For the same body the semidiameter varies with the distance; thus the difference in the semidiameter of the sun at different times of the year is due to the change of the earth's distance from the sun, and similarly for the moon and planets. In the case of the moon the radius of the earth bears an appreciable and considerable ratio to the body's distance from the earth's centre; hence the moon is appreciably nearer to an observer on the surface when she is in or near his zenith than when in or near his horizon, and therefore the semidiameter, besides having a menstrual change, has a semidiurnal one also. The increase in the moon's semidiameter, due to her increase of altitude, is called *her augmentation*. In taking altitudes and distances of heavenly bodies, the *limbs* of bodies having a visible disc are the subject of observation; therefore to reduce observed altitudes and distances to the apparent altitudes and distances of the centres, the correction for semidiameter must be applied. This is the reason why the semidiameter and not the diameter is given in tables.

Semimenstrual Inequality (L. *semi*, "half"; *menstrualis*, "monthly", from *mensis*, "a month").—An inequality (of the tide), which goes through its changes every half month.

Sensible Horizon (L. *sensibilis*, "that may be perceived through one of the senses").—The plane touching the earth at the station of the observer.—See **Horizon.**

Serpens (L. "The Serpent" of Ophiuchus).—A constellation lying to the east of the line joining Arcturus and Antares. *α Serpentis*, mag. 2.3; 1882, R.A. $15^h\ 38^m$, Dec. + 6° 48′.

Set of a Current.—The direction of a current, named after the point towards which it is running.—See under **Current.**

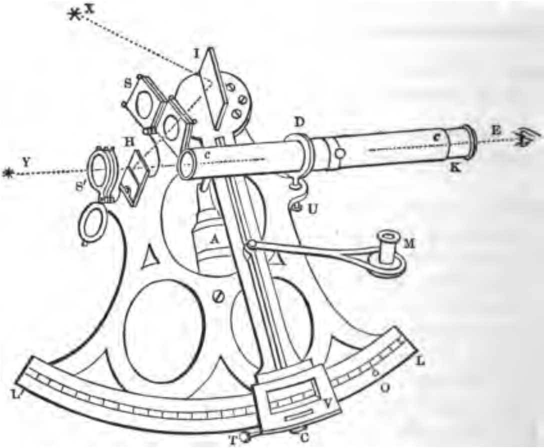
Setting.—A heavenly body is said to be on the point of setting when its centre is in the western part of the celestial horizon.—See **Rising.**

Setting an Object.—"Setting" an object is taking a bearing of it Thus: to *set the chase* is to observe well the bearing of a vessel chased.

Sextant (L. *sextans*, "the sixth part").—A portable reflecting astronomical instrument for measuring angles, deriving its name (like the reflecting circle) from the extent of the limb, which should be "one-sixth" of the circle.—See **Sector.**

With the aid of the adjoining figure we shall point out the different parts of the instrument under the names by which they are distinguished. LL′ is the *limb* or *arc* graduated from its proper left to right from the zero point 0° through 120°; this is the *arc proper;* the limb is also graduated through a small space, called the *arc of excess*, in the opposite direction, on the other side of the zero point. According to the size of the instrument the divisions are cut (on inlaid plates of platinum) at every 10′ or 20′; and these are subdivided by the *vernier* (V) to 10″ or 20″, thus in the former case enabling us to read off angles by estimation to 5″. The vernier is carried by the *index-bar* IV, a movable radius, which also carries one of the mirrors; T is the *tangent-screw* for giving a minute motion to the index-bar after it has been clamped by the *clamping-screw*

(C) at the back of the limb. **M** is a *microscope* attached to the index-bar by an arm movable round the centre, so as to sweep the vernier through its entire length. There are two mirrors, the index-glass and the horizon-glass. **I**, the *index-glass*, stands upon and moves with the index-bar; it is fixed perpendicularly to the plane of the instrument, in such a position as to be bisected by the axis of revolution produced; **H**, the *horizon-glass*, is permanently fixed on the extreme radius facing the index-glass, with which it is parallel when the index stands at 0°, the instrument being in adjustment; the lower half only of the horizon-glass is silvered, the other half allowing objects to be seen through it. In front of the reflecting index-glass, and before the open part of the horizon-glass, work sets of *shades*; **S** the *index-shades* and **S′** the *horizon-shades*: the shades of each



set may be used singly or in combination, to moderate the brightness of an image. K is a *telescope* (a sextant-case contains several) carried by the *collar* D, which is a double ring, so constructed as to furnish the means of adjusting the *line of collimation* of the telescope. This line of collimation, *cc*, passes through the centre of the horizon-glass, meeting its surface at the same angle as the line drawn from the same point to the centre of the index-glass. Hence a ray of light reflected from the centre of the index-glass to that of the horizon-glass is again reflected along the line of collimation of the telescope. The collar is attached to a stem U, called the *up-and-down-piece*, by which the telescope may be raised or lowered till objects, seen directly and by reflection, appear of the same brightness. The two reflectors are furnished with *adjusting-screws*. A is the handle by which the instrument is held. In the American prismatic sextant the index-glass is replaced by a rectangular prism; and there is no unsilvered portion of the horizon-glass, so that the direct ray passes through no medium.

The principle of the sextant is this:—"The angle between the first and last directions of a ray which has suffered two reflections in one plane is equal to twice the inclination of the reflecting surfaces to each other." [See **Reflection.**] Thus let XIHE be a ray of light proceeding from the luminous body X, reflected first from the mirror I in the direction IH, and then again at the mirror H in the direction HE; thus X will be seen, by an eye at E, in the direction EH. Again, another body, Y, lying on this same line of direction, will be viewed coincidently with the reflected image of X by the eye at E through the open part of the glass H. Thus, when their images are brought together, the angular distance between X and Y is double the inclination of the mirrors I and H. This inclination is measured upon the limb of the instrument, and the graduations of the limb are purposely made only half the distance that corresponds to degrees; and thus, when they are regarded as degrees, the reading-off will at once give the angular distance of X and Y instead of half that angle.

The two classes of observations made with the sextant are measuring the altitudes of heavenly bodies, and the distances of certain of the heavenly bodies from the moon. The sextant, held in the hand and requiring no fixed support, is specially adapted for ship's use. For altitudes at sea, as no level, plumb-line, or artificial horizon can be used, the image of the body observed is brought into coincidence with the sea offing. The sextant is *the* instrument of celo-navigation, and for it the seaman is indebted to Sir Isaac Newton, who first proposed the construction at the beginning of last century. It is commonly called after John Hadley, who published the invention (made independently by himself, probably) a few years subsequently. About the same time, also independently, a similar instrument was made by an American glazier, named Thomas Godfrey. As there is frequently a confusion of several different things under the general head of "Adjustments of the Sextant", we must enter fully into its *Imperfections*, *Adjustments*, and *Errors*.

Sextant: (I.) **Imperfections**; (II.) **Adjustments**; (III.) **Errors.**

(I.) **Imperfections**, or essential defects which should lead to the rejection of the instrument. The following are the chief points to be tested:—

1. All the *joints* of the framework should be perfect, close, and tight, and all the *screws* should act well, remaining steady when the instrument is shaken.

2. The *centering* should be perfect. Imperfect centering may be detected by comparing the distance of two stars observed with the sextant under trial with the same distance observed with a standard sextant or circle, or deduced from computation.

3. The *graduation* on the *limb* and *vernier* should be perfect. It must be noticed that the inlaid plates upon which the divisions are marked are quite level with the surface of the instrument; then the fineness and distinctness of the cutting must be examined with the microscope, and their equality of distance throughout tested by bringing the index of the vernier into exact coincidence successively with each division of the limb, till the last division upon the vernier reaches the last division

upon the limb: if the last division of the vernier do not in each case exactly coincide with a division upon the limb, the instrument is badly graduated.

4. All the *glasses* used should be perfect. The glasses of the *reflectors* should be free from veins, and each have its two faces ground and polished parallel to one another. To test whether this is the case, look with a small telescope into each reflector separately, in a very oblique direction, and observe the image of some distant object; this image should appear clear and distinct (not notched and streaky) in every part of the reflector, and the image single and well defined (not misty) about the edges. The glass of the *shades* should in like manner be of the best quality, and each shade have its two faces ground and polished parallel to one another. Each set of shades should also work with all the faces parallel. *To examine the perfection of the shades.*—Having fitted the dark glass to the eye end of the telescope, without the intervention of any of the index or horizon shades, make a contact of the reflected and direct images of the sun. Then remove the telescope shade, and, setting up first each fixed shade separately, and then their various combinations, observe whether the images remain in contact in each case. Should a divergence be observed in any case, if it occurs when a single shade is used, such shade should be rejected; if it occurs when a combination is used, the setting of the shades should be altered. This source of error may, however, be allowed to remain, and acknowledged under the head of *Shade Error*, and corrections applied for it to every observation.

(II.) **Adjustments** where a machinery is attached to the instrument by which it may be put into order. We often read, " The adjustments should be made by an instrument maker, as they require the greatest care," etc. We entirely disagree with this; every midshipman should learn to adjust his own sextant, and even to re-silver his glasses.

1. *The " index-glass "*, or movable reflector at the centre of the instrument, *should be perpendicular to the plane of the arc. Criterion.*—Having brought the vernier to about 60°, and holding the sextant in the left

hand with the face upwards, look obliquely into the index-glass, thus viewing the limb by direct vision to the right, and by reflection to the left. The image and the arc itself should appear in the same plane as a single unbroken arc: if the reflection seems to droop from the arc itself, the index-glass leans backward; if it seems to rise, the index-glass leans forward. *Means of adjustment.*—Screws attached to the reflector.

2. *The "horizon-glass"*, or fixed reflector, *should be perpendicular to the plane of the arc. Criterion.*—The first adjustment is supposed to be made. Holding the instrument horizontally, look through the telescope and the horizon-glass at a well-defined distant object. The most convenient objects for the purpose are the sea-horizon and the sun. (*a*) When the sea-horizon is used, set the index at zero and give the instrument a slight nodding motion. The reflected image should appear neither above nor below the real object. For this method of testing there must be no index-error, which caution is unnecessary when (*b*) the sun is used. With the left hand bring the index nearly to the zero point, and move it "handsomely" backward and forward. The image of the sun must pass directly over the object itself: if the image be the lower, the horizon-glass leans forward; if it be the higher, the glass leans backward. *Means of Adjustment.*—Screws attached to the reflector.

3. *The "line of collimation" of the telescope—i.e.* the path of a visual ray passing through the centre of the "object-glass" and the middle point between the cross wires—*should be parallel to the plane of the arc. Criterion.*—Let the telescope be firmly screwed into its place, and the wires in the diaphragm be set parallel to the plane of the sextant by turning round the "eye-tube". Then (*a*) fixing upon two distant bright objects from 100° to 120° apart, bring the reflected image of the one to an exact contact with the image of the other object. The angular distance between the two objects is only truly measured when this contact is at the centre point between the wires, which may be tested by noting that the same degree of divergence takes place at the middle points of the upper and lower wires. The sun and moon, when at a considerable

distance from each other, are the best objects, and (*b*) the best practical method of verifying this adjustment is as follows:—Bring the darkened image of the sun to touch the moon, viewed directly, at the middle point of the lower wire, and then, by moving the instrument, instantly bring the point of contact to the middle point of the upper wire: there must be an exact contact here also, the image having overlapped in the centre of the field. If the images appear separated at the upper wire, the object end of the telescope droops: if they overlap, it rises. This disarrangement always causes the observed angle to be *too great*. *Means of adjustment.*—The double collar in which the telescope is fixed is furnished with opposing screws, one of which is loosened while the other is tightened.

4. *For distant objects, when the horizon-glass and index-glass are parallel, the zero of the vernier should coincide with the zero of the arc. Criterion.*—The foregoing adjustments being in order, set the zero of the vernier to the zero of the arc, and look at a distant object, as the sea-horizon or a heavenly body; then the reflected and direct images should appear to coincide with each other. *Means of adjustment.*—Screws attached to the horizon-glass. If this adjustment is not made, there will be an error in the place of the beginning of the graduation, but this error will affect all angles observed alike. Again, it is only for very distant objects that the direct and reflected images coincide when the mirrors are parallel; for a near object the distance between the mirrors subtends a sensible angle, or has a sensible *parallax*, and therefore, for every particular distance under about half a mile, a fresh adjustment would have to be made; but it is very objectionable frequently to work adjusting-screws. Once more, the expansion and contraction of the bar causes fluctuations in the position of the index. For these reasons it is customary to admit the existence of this source of error, determine its amount, and apply a correction for it, which is called the *Index-Correction.*—See III. 2.

(III.) **Errors** acknowledged and determined, and their effects allowed for or eliminated.

1. *Shade-Error* (see I. 4).—If imperfect shades cannot be replaced by perfect ones, or bad setting rectified, the error must be acknowledged and a correction applied. In examining the shades (as pointed out above), if the reflected and direct images of the sun do not in any case remain in contact, the angle through which the index must be moved to restore the contact is the error of the shade, or combination of shades, used, which error should be recorded for each shade, and each combination of shades. Let s be this angle in any one case, reckoned positive when ranging in the same direction as the graduation of the limb, negative when in the opposite direction; then s, with the contrary sign, is the *Shade-Correction* to be applied to an observation.

2. *Index-Error* (see II. 4).—The two objects generally used to determine the index-error are (*a*) the sea-horizon, and (*b*) the sun. (*a*) *By the sea-horizon.*—Holding the instrument perpendicular to the horizon, bring the direct and reflected images of the offing into exact continuation with each other. The reading-off e is the index-error, reckoned positive if it ranges in the same direction as the graduation of the arc, negative if in the opposite direction; and e, with the contrary sign, is the *Index-Correction* to be applied to an observation. (*b*) *By measuring the sun's diameter.*—Fitting the telescope and arranging the shades so that the reflected and direct images of the sun may be viewed clearly, and seem of the same brightness, hold the instrument horizontally. The *horizontal* diameter is chosen, because the vertical one may be distorted by refraction. Now, if the index be placed at 0°, when there is no index-error the centres of the reflected and direct images of the sun will be coincident; when there is an index-error the centres will not coincide. In the latter case, if we could make an exact superposition of one image upon the other, the reading-off would give us the divergence of the centres, or the index-error of the instrument. But this cannot correctly be done, and therefore the following method is adopted: Let the left limb of the reflected image of the sun be brought into exact contact with the right limb of the direct image, then read off; again, bring the right limb of the reflected image into exact contact with

the left limb of the direct image, then read off once more. If (as is generally the case) one of these readings is on the arc proper, and the other on the arc of excess, half their difference is the index-error, and the corresponding index-correction is subtractive or additive according as the reading on the arc proper is greater or less than that on the arc of excess. Should the readings be both on or both off the arc, half their sum will be the index-correction, subtractive when *on*, additive when *off*, the arc proper. Several sights should be taken *on* the arc, and the same number *off* the arc, and a mean of the readings used; also the limbs should be placed (by hand, before the tangent-screw is used) alternately a little open and a little overlapping, so that in making the contact the tangent-screw may be turned different ways. When, in taking an angle with a sextant, the object viewed directly is less than half a mile distant, the index-correction in each case must be found by making the image of that object coincide with the object itself; the reading-off will then be the correction required.

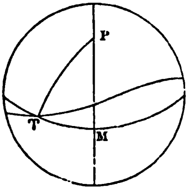
Shades.—Sets of coloured glasses attached to astronomical reflecting instruments for the purpose of diminishing the glare of an object, and equalizing the brightness of the direct and reflected images. The set which is fitted to cover the index-glass may be called the *Index Shades*, those which are fitted to cover the horizon-glass the *Horizon Shades*. If these shades are made of bad glass, and their faces not ground parallel, observations made when they are used will be affected with an error, which may be called the *Shade-Error*. [See under **Sextant**, III. 1.] Besides these there is the *Telescope Shade*, a dark glass which can be screwed on to the eye end of the telescope. When this is employed alone there can be no resulting error; for if the faces of the glass are not perfectly ground, the rays from the direct and reflected image are affected alike, and the measured angle between them remains unchanged.

Shaping the Course.—"Shaping" the course is the determining on what course to put the ship's head for a given passage.

Sidereal (L. *siderālis*, from *sidus*, *sidĕris*, "a star").—Pertaining to the stars; thus we have "sidereal day", "sidereal year", "sidereal time".—See under each term qualified.

Sidereal and Solar Day; Sidereal and Solar Year.—The significance of the adjectives must be carefully noted and distinguished in these two sets of expressions. The retrograde motion of the first point of Aries separates it from any fixed star on the ecliptic by 50·1″ annually, a quantity which is the express cause of the difference in length of the solar and sidereal year, and which must therefore, in their case, be strictly taken into account. But the corresponding *daily* motion of the first point of Aries is so small that it is neglected, and the sidereal day is defined by the successive transits of this point. The solar year differs from the sidereal year by reason of the annual motion of the first point of Aries; the solar day differs from the sidereal day by reason of the sun's daily motion in the ecliptic, which is independent of the diurnal revolution of the celestial concave. The first point of Aries, therefore, marks the commencement of the sidereal *day* and of the solar *year*.

"Sidereal Time" at Mean Noon.—The sidereal time at mean noon, given in the "Nautical Almanac", p. II., of the month, is the time shown by a sidereal clock at Greenwich when the mean solar clock indicates $0^h\ 0^m\ 0^s$. It may be defined as the angular distance of the first point of Aries from the meridian of Greenwich at the instant of mean noon (MP♈). It is therefore the same (though reckoned in the opposite direction) with the right ascension of the mean sun when it is mean noon at Greenwich (♈M). "The right ascension of the mean sun" must not be confounded with "the right ascension of the sun at mean noon".



Signs of the Ecliptic or Zodiac.—The ecliptic is divided into twelve equal portions called "signs", each occupying 30° of its circumference, commencing from the vernal equinoctial point, or first point of Aries. The names of the signs, in order, with their several symbols, are as follows:—*Aries* ♈, *Taurus* ♉, *Gemini* ♊, *Cancer* ♋, *Leo* ♌, *Virgo* ♍; *Libra* ♎, *Scorpio* ♏, *Sagittarius* ♐, *Capricornus* ♑, *Aquarius* ♒, *Pisces* ♓. The first six are the northern, and the last six the southern signs. These are the names also of the twelve *Constellations of the Zodiac;* and when this notation was established, "the signs of the ecliptic", or, as they are sometimes called, "the signs of the Zodiac", coincided in position with the "constellations" of the same name, which name, consequently, the sign took. This coincidence, however, no longer exists. The vernal equinoctial point, or first point of Aries, from which the divisions of the ecliptic commence, has a slow retrograde motion along the ecliptic, so that it is no longer in the constellation of Aries, but is now situated in that of Pisces, and so for all the "signs" whose position is defined by that of the origin; they have retrograded with respect to the corresponding constellations, or, which is the same thing, the constellations have progressed relatively to them, the constellation of Aries now occupying the sign Taurus, the constellation of Taurus the sign Gemini, and so on. Hence it must be particularly observed that the signs of the ecliptic are now regarded as purely *technical* subdivisions, and not to be confused with the constellations of the same name, though they were originally identical. In former times it was usual to note the longitude of a heavenly body in *signs, degrees, minutes*, etc., 5^{s} 15° 20′ indicated what would be now written 165° 20′. The old nomenclature still, in some measure, holds its ground. The equinoctial points are generally called the *first point of Aries*, and the *first point of Libra*; the two parallels of latitude on the earth's surface called the *tropics* retain the names of the *Tropic of Cancer* and the *Tropic of Capricorn*, after the constellations in which the solstitial points were formerly situated; and again, in speaking of the place of the sun, it is often referred to the signs—"the sun is in Aries", means that he is between 0° and 30° of longitude

Sirius (Gk. Σείριος, from σείρειν, "to scorch"; or **Canicula**, L. the "*Dog Star*").—The star *α Canis Majoris*, the brightest in the heavens. In ancient times the heliacal rising of this star (*i.e.* when it rises so much before the sun as to become visible just before daylight) followed close upon the summer solstice, the season of the greatest heat. The Egyptians called it "*Sothis*", and from its heliacal rising had warning that the overflow of the Nile was about to commence. Owing to the procession of the equinoxes, the heliacal rising of Sirius has slowly changed, its date at present taking place about August 10.—See **Canis Major.**

Slack-water.—The time of slack-water at any place is that interval during which there is no tide-current. It must not be confounded with the time of high or low water.

Small Circles.—Small or Less Circles of the Sphere are those whose planes do not pass through the centre.—See under **Circles.**

Solar (L. *solaris*, from *sol*, "the sun").—Pertaining to the sun. Thus we have the *Solar System*, designating all those heavenly bodies which revolve about the sun as their centre. Again, the *Solar Year* and *Solar Day* are portions of time marked and defined by the apparent motions of the sun; so we have *Solar Eclipses*, the *Solar Disc*, etc.

Solstices (L. *solstitium* = *solis statio*, from *sol*, "the sun", and *stare*, "to stand still").—The two periods of the year, about June 21st and December 22nd, at which the sun attains his maximum declination north and south. When the sun, in his annual revolution in the ecliptic, after travelling north, has attained his greatest northern declination, his course for the moment is parallel to the equinoctial, and, as far as change of declination is concerned, he appears "to stand still"; and similarly he appears "to stand still" when at his greatest southern declination. They are distinguished as the *Summer Solstice* and the *Winter Solstice*. We must bear in mind, however, that these terms are relative, for what is the summer solstice in the northern is the winter solstice in the southern hemisphere, and what is the winter solstice in the northern is the summer solstice in the southern hemisphere. Hence, at first sight, it would appear better to distinguish the solstices as the *northern* and *southern solstice*, but then the significance of these epochs would be lost. They are, be it remembered, epochs of the *tropical* year, which year has especial reference to the succession of the *seasons*, and therefore, as in the case of the equinoxes, the seasons which they mark must be the qualifying adjective; thus, as we have the *Vernal* and *Autumnal Equinoxes*, so we must have the *Summer* and *Winter Solstices.* In cases where there is any danger of ambiguity or confusion, we may add northern or southern, as the case may be: thus one date will be called the *Northern Summer Solstice* or the *Southern Winter Solstice*, and the other the *Northern Winter Solstice* or the *Southern Summer Solstice.* It is convenient to restrict (as we have done) the term *solstice* to indicate a date or epoch of *time*; and to use the expression *solstitial point* when we want to refer to a *position* or *place* in the ecliptic. Similarly for *equinox* and *equinoctial point.*

Solstitial Colure.—The hour-circle which passes through the solstitial points. On it are situated not only the poles of the equinoctial, but also those of the ecliptic.—See **Colures.**

Solstitial Points.—The two points of the ecliptic at the greatest distance from the equinoctial. They are distinguished as the *Summer Solstitial Point* and the *Winter Solstitial Point*, and called also the *First Point of Cancer* and the *First Point of Capricorn*, as being the commencement respectively of these signs of the ecliptic. They are represented by the symbols of these signs ♋ and ♑. The figure of the *Crab* (Cancer) has evident reference to the change in the direction of the sun at this point of his orbit. The solstitial points, like the equinoctial points, do not preserve a constant place among the stars, but have a regular slow retrograde motion.

Sound.—Whatever be their loudness or pitch, all sounds are propagated with the same velocity through the same medium. This velocity has been determined for the atmosphere by experiments. The conclusion is that sound travels in dry air, at the temperature of freezing water, about 1090 feet per second; and that, supposing the pressure of the atmosphere constant, the velocity increases with the temperature at the rate of 1·14 feet (very nearly) per second for every 1° Fahrenheit. At an average temperature of 62°, sound will travel at the rate of 1125 feet per second.

Whatever tends to increase the *elasticity* of the air also accelerates the motion of sound through it. A moderate breeze direct between the origin of the sound and the listener affects the velocity about 20 feet a second. It is obstructed by whatever disturbs the homogeneity of the medium, such as partial variations of temperature. Sounds are better heard during the night than in the day time; and snow, fog, and rain, when general, are particularly favourable for the transmission of sound. These facts furnish a method, with cautions in using it, which is sometimes convenient for estimating distances. If the number of seconds be noted which elapse between seeing the flash of a distant gun and hearing the report, the distance of the gun is easily deduced. The following approximate rule is useful for practical purposes:—Divide the seconds elapsed by 5; from the quotient substract $\frac{1}{12}$ of itself, and the result is the distance in statute miles very nearly; if $\frac{1}{12}$ of the quotient be added instead of subtracted, the result is nautical miles.

Sounding (Sax. *sond*, "a messenger"; Fr. *sonder;* Sp. *sondar* or *sondear*).—Sounding is the ascertaining particulars respecting the bottom of the water through which a ship is sailing. The results of ocean-sounding will doubtless prove indirectly important to the seaman, but for the direct purposes of navigation we are concerned only with (1) Soundings in shallow water, with a view of safely guiding the ship over shoals, through channels, to an anchorage, etc.; (2) Soundings in deeper water, with a view of determining the position of the ship.

1. In **Safety-Soundings** it is evident that it will often be sufficient to know that the depth is *above* a certain value, but when it shallows to near the draught of the vessel, great attention must be paid to the soundings. They are found by the simple instrument called the *Hand-Lead.*

2. In **Position-Soundings** the information is sought on two points—the depth of the water and the nature of the bottom. The instrument used is the *Deep-sea Lead.* In the common deep-sea lead the depth of the water is indicated by the length of the measured and marked line run out, and the nature of the bottom is ascertained by the portion brought up by the "arming" of the lead. To obviate the necessity of stopping the ship's way and "rounding her to" when thus sounding, several ingenious instruments have been invented. In *Burt's Buoy and Nipper* the line runs through a spring catch in a buoy till the lead reaches the bottom, when the catch seizes the line and fixes the buoy at the depth descended. *Massey's Lead* registers the depth of water descended through by wheelwork set in motion by a fly. *Walker's Harpoon-Sounding Machine* is on the same principle. *Ericson's Lead* measures the depth of the water by the space into which the air contained in a glass tube and reservoir within the lead is condensed by the pressure of the water. *Sir William Thomson's Sounding Machine* has a glass tube connected with the sinker, closed at the top end and coated inside with chromate of silver; the increased pressure at greater depths drives the water up the tube, and its action leaves a white mark, the position of which can be estimated by a scale; pianoforte steel wire is used instead of line and is coiled on a light reel. The methods of estimating the depth by the increased pressure, being independent of the amount of line out, does not necessitate stopping or reducing the speed of the vessel.—See **Lead.**

South Frigid Zone.—The zone of the earth contained between the south pole and the antarctic circle, or parallel of about 66° 32′ S.

South Temperate Zone.—The zone of the earth contained between tropic of Capricorn, or parallel of about 23° 28′ S., and the antarctic circle, or parallel of about 66° 32′ S.

South Point of the Horizon.—The *north* and *south* points of the horizon are the points in which the meridian line meets the celestial horizon; the south point being that adjacent to the south pole of the heavens. When the north pole is above the horizon, the south point is the origin from which azimuths are reckoned.

South Pole of the Earth.—That pole which is furthest from Europe.

South Pole of the Heavens.—That pole of the heavens towards which the south pole of the earth is directed.

Southern Hemisphere.—Of the two hemispheres into which the earth is divided by the equator, the *southern* is the one in which Europe is not situated.

Southing.—The distance a ship makes good in a south direction; it is her difference of latitude when going southward. Opposed to *northing.*

Sphere.—(Gk. *σφαῖρα*, "a ball").—A solid body contained by one uniform round surface, every point of which is equally distant from a certain point within it called the centre; it may be conceived as generated by the revolution of a circle about a fixed diameter. The doctrine of the sphere treats of its properties considered as a geometrical surface. In astronomy by "*The Sphere*" is commonly understood the "*Celestial Sphere*", or "*Concave*". The *Right Sphere* is the sphere in that position in which the diurnal circles are at right angles to the horizon; the *Parallel Sphere* the sphere in that position in which they are parallel to the horizon; and the *Oblique Sphere*, the sphere in that position in which they are oblique to the horizon.

Sphere of the Heavens, or **of the Stars.**—The imaginary sphere of infinite radius, having the eye of the spectator for its centre, on the concave surface of which the heavenly bodies appear to be placed. It is also called the "*Celestial Concave*". The radius of the earth being evanescent relatively to the distance of the celestial concave, the eye of the spectator and the centre of the earth are considered coincident.

Spherical Sailing.—The method of solving problems in navigation upon principles deduced from the spherical figure of the earth. All problems not involving Difference of longitude may be determined upon the supposition that the elements all lie on a plane requiring the application of plane trigonometry only; hence the relations of the quantities, Course, Distance, Difference of latitude, and Departure, are treated of under the head of *Plane Sailing.* The aid of spherical trigonometry, either in the actual computation or in the construction of the tables used, is necessary when the Difference of longitude is involved, and hence the relation of any two of the quantities, Course, Distance, Difference of latitude, and Departure, with the Difference of longitude, are treated of under the head *Spherical Sailing.* The simple case of *Parallel Sailing* (where a property of the sphere exhibits a constant relation between the Departure and Difference of longitude, and which two quantities may therefore be treated as elements of a plane triangle) furnishes a kind of link between plane and spherical sailing. From this particular case is deduced an approximate method of solving the general problems of spherical sailing called *Middle-Latitude Sailing.* The accurate method is called *Mercator Sailing*, from the chart constructed on the principles made use of.—See **Sailings.**

Spheroid (Gk. *σφαιροειδῆς*, "ball-like"; from *σφαῖρα*, "a ball", and *εἶδος*, "form").—A solid body which approaches the form of a sphere. It may be conceived to be generated by the revolution of an ellipse about one of its axes. If the ellipse revolve about the major axis, a *Prolate Spheroid* is generated; if about the minor axis, an *Oblate Spheroid.* The oblate spheroid is the more important, as being the forr which a mass of plastic matter would assume by rotating on a given axis, and consequently it is the form of most of the heavenly bodies.

Spica. (L. "an ear of corn").—The name of the bright star *α Virginis*, so called after the device of the ancient Greeks, who placed an ear of corn in the hand of the Virgin, typical of the harvest, which with them coincided with the sun's approach to this conspicuous star.—See **Virgo.**

Spiral Curves.—Curves which circulate round a point or pole following some distinguishing law. On the surface of the earth an *equiangular spiral* is a curve which cuts all the meridians at equal angles while it winds round and round the globe approaching the pole asymptotically: it is best known as the rhumb.

Spring Tide (Sax. *springan*, "to grow", "bulge").—The greatest tides, taking place after the syzygy of the sun and moon.—See under **Tides.**

Stars, Fixed.—Those bodies of the heavens which possess a high degree of permanence as to apparent relative situation. The term "fixed" must be understood in a comparative and not in an absolute sense, as doubtless every body of the universe is in a state of motion. In consequence, however, of their enormous distances, the proper motions of the "stars" produce an extremely small apparent change of relative positions to an observer on the earth's surface, and for all practical purposes they are appropriately designated as *fixed.* Their apparent position is also unaltered (except in a very minute degree in some few cases) by the parallactic change of view caused by the motion of the earth in her orbit, though she shifts her place by about 180 millions of miles in the course of the year. The nearest of the fixed stars, *α* Centauri, is distant about 200,000 times the distance (about 93 millions of miles) of the earth from the sun, others are perhaps 1000 times more remote; and in consequence they appear, when viewed through the most powerful telescopes, only as bright points without any apparent disc. They shine by their own light like our sun, and their twinkling at once distinguishes them from the planets, which are visible merely by reflected solar light. The stars exhibit different grades of brightness, and are hence ranged by astronomers into classes called "magnitudes". [See **Magnitude.**] The telescope reveals to us that the stars are innumerable, but it is only with the most conspicuous that the navigator is directly concerned. These are marked out into artificial groups called "constellations", and each member of such group is distinguished by a letter of the Greek alphabet, and in some cases by a proper name. It is necessary for us to acquire a knowledge of the names and positions of such fixed stars as are useful in the problems of celo-navigation, and of which stars full particulars are given in the "Nautical Almanac".

1. We may do this by calculating the distance of the first point of Aries from the meridian of our station at any given hour, and ascertaining, by means of the catalogue of the right ascensions and declinations, what stars must at that time be above the horizon and near the meridian, and then, by comparing their right ascensions and declinations, we may easily learn the name of each particular star. In consequence of the sun's motion in the ecliptic (in direction contrary to the diurnal motion), the fixed stars rise earlier every successive night.

2. The simplest plan, however, of becoming acquainted with the stars is by means of a globe or map of the heavens. One or two remarkable groups (such as Ursa Major and Orion) can be at once recognized, and then we can refer any star, the name of which we wish to know, to some other stars already known, by imagining a line to pass through two or more such known stars, and, when produced to a certain distance, to pass through or near the star whose name is required.

3. The Milky Way is also of great assistance to seamen in finding a star, especially on a bright night.

The altitudes of stars may be most advantageously observed at sea during the twilight, as the horizon at that time is in general clearly visible and strongly marked.

Star Charts.—The zone in the vicinity of the equinoctial may conveniently be mapped down on Mercator's projection. This is an important portion of the heavens, especially in connection with finding the longitude by lunar distances. We have consequently given a chart to illustrate *Lunar-Distance Bodies.* This is necessarily on a very small scale, but every young officer can draw a large one for his own use. The chart given comprises a zone of 90°; and it shows the lunar-distance zone of 60° with the ecliptic and zodiac running athwart it.

The circumpolar regions are best represented on circular charts. Two are given in the commencement of this book for north and south declinations. Each includes 90° of the heavens, viz. 45° from the pole. These charts are mounted as circular rotating discs, and by setting them the appearance of the heavens in the regions delineated can be obtained for any date at the place of observation. It will be easy for any navigator to construct similar discs on a larger scale.

Stereographic Projection (Gk. στερεὸς, "solid"; γράφειν, "to grave"). —The stereographic projection of the sphere is a natural projection of the concavity of the sphere on a diametral plane as primitive, the eye being placed on the surface at the opposite extremity of the diameter perpendicular to the primitive.—See under **Projection.**

Storms, Law of.—Revolving storms or cyclones (including the Hurricanes of the West Indies and South Indian Ocean, the Typhoons of the China Sea, and the Storms of the Bay of Bengal) appear to be subject to a law of which the two following points are the characteristics: (1) The wind revolves in a spiral curve round and towards an axis with great rapidity, in a direction *against* the hands of a watch in the northern, and *with* the hands of a watch in the southern hemisphere: the nearer the centre or vortex the more violent is the wind, while the centre itself is calm, the barometer descending as the centre is approached. The diameter of this whirl or gyration is in some cases as much as a thousand miles, while in others it is only a few leagues. (2) While thus rotating, the storm is carried bodily along, the axis leaning forward. These storms originate somewhere between the parallels of 10° and 20° north and south, and first travel westward in both hemispheres, increasing, however, their distance from the equator until they reach the parallel of 25° or 30° north and south, when they turn towards the east or "recurvate", but continue to increase their distance from the equator;—in other words, they first travel westwardly, inclining towards the nearer pole, and then recurve and travel eastwardly, still inclining towards the pole. The rate at which they advance appears to be different in different seas, and also to depend upon the age or period of the progress; 200 miles a day is an average rate, but in some cases it approaches 1000 miles a day.

When a ship is caught in one of these revolving storms, the great object is to avoid the vortex, where the sea is most confused, and where a sudden and violent change of wind occurs from an opposite quarter. If the ship scuds, she will obviously run round and round the vortex; if compelled to heave-to, that tack should be selected on which the wind draws aft, because, from the extreme violence of the wind, there is danger, if it head the ship, of her getting stern-way: while the ship can run, the object should be to make for the nearest limit or edge of the storm. Running, however, is attended with risks (being dismasted, upsetting, broaching-to), especially in higher latitudes, where the path of the storm is variable. The following is the rule for determining the bearing of the centre, given in the Admiralty Remarks on Revolving Storms, 1853:—"Look to the wind's eye; set its bearing by the compass; take the 8th point to the *right* thereof, and that will be the bearing of the centre of the storm, if in north latitude; or, if in south latitude, the 8th point to the *left* of the direction of the wind."

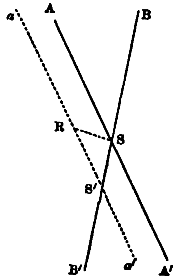
It is advisable on the first warning of the approach of a cyclone to heave-to, in order to determine accurately its position and motion. The manner in which the wind is veering is an important indication. The simplest way to understand how the wind veers as a circular storm pa over the ship is the following:—On a circle mark the direction of the whirl (for the hemisphere) by arrows; and draw a diameter in the direction of the track of the storm, which may be deduced approximately from the locality. It must be borne in mind that, for both hemispheres, the track curves in the opposite direction to the whirl. It is the *relative* motion of the progression and of the ship (hove-to) with which we are now concerned, and we may therefore consider the storm to be at rest and the ship to be moving in the contrary direction. If we then pass a pencil along any chord of our whirl-disc in the opposite direction parallel to the track of the storm, this will point out to us how the wind veers in any part of it. It will thus be found that *the wind always veers in the same direction as the storm rotates, on that side of the path which is external to its curvature; and in the opposite direction within the curvature.* If we note therefore how the wind is veering, we shall be able to conclude in what part of the storm we are hove-to. The star-discs of the commencement of this volume may serve as storm whirl-discs, the direction being the same for rotation of stars and of wind in each hemisphere.

Stratus (L. "laid flat").—The "Flat Cloud", one of the primary modifications of cloud.—See **Cloud.**

Stray-line.—The waste portion of the log-line which runs off while the log-ship is getting clear of the eddy caused by the wake.—See under **Log.**

Summer Solstice.—With reference to the northern hemisphere, the summer solstice is that period of the year when the sun attains his greatest northern declination—about June 21st.—See **Solstices.**

Sumner's Method.—The method of finding a ship's position at sea by the projection of the "line of equal altitude" on a Mercator's chart is named after Captain Thomas H. Sumner, U.S.N., who first reduced it to a system, and made it public in 1843. The principle was, however, independently applied by others about the same time. When the latitude, longitude, and apparent time at the ship are uncertain, one altitude of the sun, with the true Greenwich time, determines by this method a "line of position", the errors of longitude by chronometer consequent upon any error in the latitude, and the sun's true azimuth. When in soundings, if the lead be hove at the time the set of sights is taken, the exact position of the ship may be determined. When two altitudes are observed, and the elapsed time noted, the true latitude is projected; and if the times be noted by chronometer, the true longitude is also projected at the same operation. The manner of finding the approximate projection of a line of equal altitude on the Mercator's chart is as follows:—Assume a latitude about 10′ greater than the estimated latitude, and with this, the observed altitude, and declination of the sun, calculate the longitude. Mark the spot corresponding to this latitude and longitude on the chart (A). Again, assume a latitude about 10′ less than the estimated latitude, and find the longitude as before; mark the spot corresponding to this latitude and longitude on the chart (A′). The line joining these two spots (AA′) will be a line of equal altitude, and on or near this, or this produced, the ship is situated. Now, let a second observation of the altitude be obtained one or two hours after the first, then with this, the same assumed latitudes as before, and the sun's declination, two other spots (B and B′) may be found, and the line joining them (BB′) will be a second line of equal altitude, and on or near this, or this produced, the ship is also situated. The position of the ship is therefore given by the intersection of the two lines (S). If the ship has moved in the interval, the projection of the first line of equal altitude must be moved parallel to itself in the direction of and through the distance of the run (SR), and the intersection of its new position (*aa′*) will give the place of the ship at the second observation (S′). The pair of lines of equal altitude used



may be those corresponding to the altitudes of two bodies observed at the same time; and two bright stars taken at twilight are very useful for this purpose.

Sumner adopted for the curves used in this method, the name of *Parallels of Equal Altitude*, which is also used by Raper and others. Another appropriate name for them is *Circles* or *Arcs of Position*.—See under **Position**.

Sun (Sax. *sunna ;* Latin analogue, *sol*, whence *solar*).—The vital centre of that group of heavenly bodies of which our earth is a member. Its actual diameter is about 109 times that of the earth, or 860,000 miles, and its mean distance from us no less than 23,584 times the length of the earth's radius, or about 93,300,000 miles. The apparent diameter varies from 31′ 32″ (in the beginning of July) to 32′ 36·4″ (in the beginning of January), and the horizontal parallax is 8·76″. The figures here given are from Report of Astronomer Royal on Transit of Venus, 1874. The sun is the most important body for the purposes of celo-navigation; and full particulars are given respecting it, for every day in the year, in the "Nautical Almanac". Each column must be thoroughly understood. Symbol ⊙.

Superior (L.).—An adjective often used to qualify scientific terms, indicating "above", "upper", "outer"; and opposed to *Inferior*, which indicates "below", "lower", "inner". Thus we have the *superior tide* when the moon is above the horizon, the *superior culmination* of a circumpolar star, the *superior planets* whose orbits are external to that of the earth, and the *superior conjunction* of an inferior planet.

"**Swinging the Ship.**"—An operation for determining the deviation of the compass on board ship. There are two principal methods of conducting it.

1. The magnetic bearing of a conveniently distant object being determined, the ship is carefully swung to each point of the compass, and on each the bearing of the object is noted. The difference between the magnetic and the observed bearing will be the deviation for each point.

The magnetic bearing of the object is found: (*a*) By taking the mean of those observed bearings that are on equidistant points, the effects of deviation being thus eliminated; or (*b*) By carrying the standard compass on shore to some place (free from "local attraction") where the distant object and the position of the compass on board are exactly in the same line with the observer's eye. This is evidently the same as the magnetic bearing of the object from the ship.

The object selected should be at such a distance that the diameter of the space through which the compass revolves in swinging makes no sensible difference in the bearing.

2. A more reliable method ("Reciprocal Bearings") is to call in the aid of a second compass, placed on shore, beyond the influence of the iron on board the ship. The two compasses should be compared by taking the bearing of a distant object with each of them on shore. The shore compass should not be further off from the ship than is consistent with distinct visibility, with the naked eye, of both compasses from each other. As the ship's head is then successively brought to each point of the compass, as indicated by the compass on board, an observer on shore takes the bearing of the compass in the binnacle, and a person on board simultaneously (the instant being known by concerted signal) takes the bearing of the compass on shore (indicated by a flagstaff). Each bearing observed from the ship is afterwards compared with the opposite of the corresponding bearing from the shore, and the result is a table of deviation for every direction of the ship's head. If during the operation a haze obscures the shore-compass, while the sun at the time is shining brightly, a number of points may be secured by time-azimuths, which otherwise might be lost.

Time-azimuths are also advantageous when the second of the ab methods cannot be used for want of an assistant observer for the shore-compass; and when the first of the above methods is not available owing to the length of the ship (*e.g.* the Great Eastern) and the scope of moorings, combined with the most distant objects in sight not being sufficiently far off to render the difference of their bearings insensible as the ship swings round to the tides. In such cases Godfray's ***Azimuth Diagram*** will be found very useful.

Syzygy (Gk. *συζυγία*, "a yoking together"; from *συν-*, "together", *ζυγὸν*, "a yoke").—The position of the sun, earth, and other moving bodies, when their projections on the plane of the ecliptic are in one line. By the *syzygies* of a planet or of the moon are meant those points of its orbit at which the body is in conjunction or opposition with the sun; the two points when the body appears 90° from the sun being distinguished as the *quadratures*. "The moon in syzygy" expresses the position *both* of conjunction and opposition, the times *both* of new and full moon; and the term, consequently, is a very handy and appropriate one in speaking of the tides.

Syzygy Tide.—The tide which takes place on the afternoon of the day the sun and moon are in syzygy: if the syzygy takes place when the sun or moon is on the meridian, the tide is particularized as the ***Meridional Syzygy Tide.***—See under **Tide.**

T.

t.—Of the letters used to register the state of the weather in the log-book, t indicates "*Thunder*".

Taurus, Constellation of (L. "The Bull").—The second constellation of the ancient zodiac, lying between Aries and Gemini. This group is easily identified in the heavens, as it contains the two beautiful little clusters of minute stars called the *Hyades* and the *Pleiades*; and in the former is situated the bright ruddy star *α Tauri*, named also *Aldebāran*. A line joining Aldebaran and Sirius is bisected by the middle star of Orion's Belt. *α Tauri*, mag. 1; 1882, R.A. 4^h 29^m, Dec. + 16° 16′. *β Tauri*, called also *Nath*, is near the bisection of the line joining *Betelgeux* and *Capella;* mag. 2; 1882, R.A. 5^h 19^m, Dec. + 28° 30′.

Taurus, Sign of.—The second division of the ecliptic, including from 30° to 60° of longitude. Owing to the precession of the equinoxes, the *constellation* Taurus is no longer in the *sign* of that name, the constellation Aries having taken its place. The sun is in Taurus from about April 20th to about May 21st. Symbol ♉.

Temperate Zones (L. *temperatus*, "moderate").—The two zones of the earth included between each tropic and the adjacent polar circle, or parallels of latitude of about 23° 28′ and 66° 32′ north and south. In these zones the sun never appears vertical, but in every diurnal revolution he rises and sets; hence their temperature is in a general way intermediate between that of the Torrid and that of the Frigid Zones, and they thus derive the name by which they are commonly distinguished.—See **Zones.**

Terminator.—The surface of the earth regarded with reference to its illumination by the sun is divided for any one instant into two parts, one enlightened and the other in shade. The corrections for parallax, refraction, and semidiameter being made, these portions are hemispheres, and they are divided from each other by a great circle. This great circle is called by older writers, such as Robertson, the *Terminator*, from its property of "terminating" or bounding the verges of light and darkness. This term has the advantage of brevity as well as of analogy to the word equator. By most modern writers the name given to it is *The Circle of Illumination*; a term descriptive and appropriate, but rather cumbersome.

The word "Terminator" has also the advantage over it of being capable of extension to a star, if it is defined as the boundary of the hemispheres in one of which at any moment the body is visible and in the other invisible.—See **Position, Parallels of.**

Terrestrial (L. *terrestris*, from *terra*, "the earth").—Pertaining to the earth; opposed to *Celestial.* Thus we have the "Terrestrial Meridian" of an observer, and the "Terrestrial Horizon", as distinguished from his "Celestial Meridian" and the "Celestial Horizon"; again, we have the "Terrestrial Equator" and the "Celestial Equator", "Terrestrial Longitude and Latitude" and "Celestial Longitude and Latitude".—See under each term qualified.

Theodolite (coined from Gk. *θεάομαι*, "I survey", *δόλος*, "a stratagem").—The most important instrument used by surveyors. It is an altitude and azimuth instrument, and by the combination of the means of measuring simultaneously vertical and horizontal angles, it gives at once the angular distances between objects projected on the plane of the horizon. There are two essential parts of the theodolite:—

1. The horizontal limb consists of two circular plates fitting accurately and turning freely upon one another round a vertical axis; the edge of the lower disc is graduated with the divisions of the circle, and the upper one has chamfered portions of its arc formed into verniers which give the name to the place.

2. The vertical limb, generally a semicircle, carrying above its diameter the observing telescope, works upon a horizontal axis which is supported upon a frame embedded in the vernier plate and turns with it in azimuth. The semicircle is graduated on one side from 0° to 90° each way, and on the other side there is given a scale for reducing the distances measured along the ground at various elevations and depressions, to the corresponding distances projected on the horizon.

The stand, levels, compass, telescopes, and other necessary fittings would require a lengthened description. For this and for the different adjustments we must refer to special books on the subject as "Mathematical Instruments", by J. F. Heather (Crosby, Lockwood and Co.).

Thermometer (Gk. θερμὸς, "hot"; μετρεῖν, "to measure").—An instrument by means of which temperature is measured. The principle upon which its construction depends is, that within certain limits bodies expand or contract with the increase or decrease of the degree of temperature to which they are subject. The common thermometer consists of a closed glass tube with a capillary or hair-like bore, terminating in a bulb at one end; the bulb and part of the tube contain mercury or coloured spirits of wine, the part of the tube not so occupied being a vacuum. A graduated scale is attached to the tube to indicate the expansion of the mercury or alcohol, which expansion is considered to be proportional to the degree of heat by which the instrument is influenced. The thermometer generally used in England is called after *Fahrenheit* of Amsterdam, who first constructed mercurial thermometers. His inferior limit of temperature was an intense degree of cold, produced by a mixture of snow and sea-salt, and which, as if it were the greatest degree of cold possible, he marked as the zero of his scale; his superior limit was the boiling point of mercury, which he marked 600°. On this scale the freezing point of water is 32° and the boiling point of water (under a certain atmospheric pressure) is 212°. In the thermometer constructed by *Réaumur* with spirits of wine, the freezing point of water is the inferior limit, marked 0°, and the boiling point of water (under a certain atmospheric pressure) the superior limit, which is marked 80°. A much more convenient scale is the *Centigrade*, invented by Celsius, a Swede. The two limits are the same as Réaumur's thermometer, "the freezing point" being obtained by immersing the instrument in melting snow; and "the boiling point" by exposing it to the steam of water boiling under a given atmospheric pressure; the freezing point is marked 0° and the boiling point 100°, the intermediate space being divided into a hundred equal parts.

To compare the indications of a Fahrenheit, Réaumur, and Centigrade thermometer.—Under the same circumstances let the three thermometers indicate respectively F°, R°, and C°. Then $F^\circ - 32^\circ$ is the number of degrees of Fahrenheit above the freezing point, and (since $212^\circ - 32^\circ = 180^\circ$) a degree Fahrenheit measures the $\frac{1}{180}$th part of the distance between the freezing and boiling point, also a degree Réaumur measures the $\frac{1}{80}$th part, and a degree Centigrade the $\frac{1}{100}$th part of the same distance.

$$\therefore \frac{F-32}{180} = \frac{R}{80} = \frac{C}{100}$$

$$\text{Hence } \frac{F-32}{9} = \frac{R}{4}; \quad \frac{F-32}{9} = \frac{C}{5}; \quad \frac{R}{4} = \frac{C}{5}$$

formulæ by means of which we can deduce the reading of one scale from that of another.

Tides (Sax. *tidan*, "to happen"; from *tid*, "time").—Semidiurnal oscillations of the ocean occasioned by the combined action of the sun and moon. The relative effects of these two bodies are directly as their mass, and inversely as the square of their distance; and the moon, although very small in comparison with the sun, is so much nearer that she exerts by far the greater influence on the phenomena of the tides. We may consider their action separately.

The attraction of the moon on different parts of the earth is less as the distance is greater, and thus it influences the parts of the ocean nearest to her more powerfully than the body of the earth, and this again more powerfully than waters most remote. The particles of water under the moon have a tendency to leave the earth, but are retained by the superior attraction of the earth; again, the moon attracts the centre of gravity of the earth more powerfully than she attracts the particles of water in the hemisphere opposite to her, so that the earth has a tendency to leave these waters, which are retained, however, by the superior attraction of the earth. The effect of this difference of the attractions on the superficial water on opposite sides, and on the central mass, is two risings of the water—the one vertically below the moon, and the other diametrically opposite to this place. If the earth were entirely covered with an ocean, the waters would thus assume the form of a spheroid, having, if the earth had no rotation, its longer axis directed towards the moon, and its shorter axis at right angles to that direction. As the moon in her apparent diurnal motion looks down successively upon each meridian, the protuberance of the ocean follows its motion from east to west; but, by reason of the inertia of the water, this occurs at a meridian about 30° to the east of the moon. This great wave, following all the motions of the moon, is modified by the action of the sun. The sun raises a similar but much smaller wave, which tends to follow his motions, and which consequently at times combines with the lunar wave, and at other times opposes it, according to the relative position of the two bodies. It must be particularly noted that the bodies do not draw after them the water first raised, but continually tend to raise that under them at the time. The tide is not a circulating *current*, but an immensely broad and excessively flat *wave*, which is propagated by the transits of the disturbing body. As this wave strikes our coast the water gradually elevates itself to a certain height, then as gradually sinks to about the same extent below its mean level; and this oscillation is continued constantly, with certain variations in the height and in the times of attaining the maxima of elevation and depression. Considering the tides relatively to the whole earth and open seas, on the meridian about 30° to the east of the moon there is high-water, on the west of this circle the tide is flowing, on the east it is ebbing, and on every part of the meridian at 90° distant it is low-water.

Tides, Neap (Sax. *neafte*, "scarcity").—The smallest tides; being the result of the action of the moon and sun when they are conflicting. They take place after the moon is in quadratures—*i.e.* after the first and third quarter of the moon. The *smallest neap-tides* happen when the moon's and sun's attractions tend most to counteract each other, which will happen when the moon's action is the least possible and the sun's the greatest possible. This will evidently be (1) When the moon is in apogee and the earth in perihelion at or near the same time; or, in other words (as the parallax of a body indicates its proximity to the earth), when the moon's parallax is the least, while the sun's is the greatest; (2) When the moon's declination and the latitude of the place are of different names, and the declination the greatest possible, at the same time that the sun's declination coincides or approximates to the latitude of the place, both being north or south; or, in other words, when the moon's meridian altitude is the least possible and the sun's the greatest, the action being the more powerful in proportion as the body is more nearly vertical. The magnitude of the tide is also affected by strong winds and the state of the atmosphere. The action of the former is most conspicuous in rivers and narrow seas; and of the latter it has been observed that a rise in the barometer of an inch has been accompanied by a depression in the water of the tide of twelve or fourteen inches.

Tides, Spring (Sax. *springan*, "to grow," "bulge").—The greatest tides being the result of the action of the moon and sun when they are co-operating, they take place after the moon is in syzygy—*i.e.* in conjunction and opposition, when it is new and full moon. The *greatest spring-tides* happen when the moon and sun are in such positions that their attractions produce the greatest effect upon the waters, especially when these positions are contemporaneous. These are—(1) When the moon is in perigee; when the earth is in perihelion. In other words (as the parallax of a body indicates its proximity to the earth), the effect of each body in raising the tide is greater as its parallax is greater. (2) When the moon's declination coincides with or approximates to the latitude of the place, both being north or south, and the sun's declination fulfils the like condition. In other words (as, generally speaking, the vertical action is the most powerful), the effect of the two bodies is greater as their altitudes are greater. The magnitude of the tide is also affected by strong winds and the state of the atmosphere; favourable winds and a low barometer are the meteorological conditions which augment the tides.

Tide, Superior and **Inferior.**—The Superior Tide is that which takes place in the hemisphere which has the moon above the horizon; the Inferior Tide is that which happens simultaneously in the hemisphere which has the moon below the horizon.

Tide-wave.—The accumulation of the waters of the sea which is caused by the action of the moon, modified by that of the sun, changes its position through the day. The moon and sun in their diurnal revolutions continually and successively tend to raise the water beneath them at the time, and thus the alteration in the level of the sea is propagated from east to west, though there is no transference of the water itself except near the shore. Interruptions in the regular propagation of the tide-wave are caused by the depth of the ocean and the barriers presented by land stretching athwart its direction.

Tide-current.—The current in a channel caused by the alteration of the level of the water during the passage of the tide-wave. Thus there is the *Current of the Flood* and the *Current of the Ebb; Slack-Water* intervening at the change from one direction to the other. The tide-current does not generally change with the tide; thus, under certain circumstances, the current of the ebb continues to run for some hours after the flood-tide has made.

Tide, Range or **Height of.**—The difference between the level of high-water and that of low-water. Speaking of the earth at large, the range is greater in those latitudes over which the moon and sun pass vertically, being very small in high latitudes. In the open ocean the range is inconsiderable, and in inland seas almost insensible. It is most affected by local causes, as the shoaling of the water and the narrowing of the channel, especially if the channel opens in the direction of the tide-wave; thus in the Bristol Channel the range is above 40 feet.

Tide, Retard or Age of.—The interval between the transit of the moon, at which a tide originates, and the appearance of the tide itself. It is found in general that any particular tide is not due to the moon's transit immediately preceding, but to a transit which has occurred some time before, and which is said therefore to correspond to it. The *Retard of the Tide* is thus distinguished from the *Lunitidal Interval*, which is the interval between the moon's transit and the high-water next following. The name *Retard* is derived from the tide appearing to be "retarded" in following the moon in her diurnal course. The cause of the phenomenon may, however, be best understood by regarding the actual rotary motion of the earth on its axis, instead of the apparent diurnal revolution of the moon in the heavens. The *momentum* of the water will cause a continuance of its rise long after it has passed under the exciting cause. On the same principle, changes in the parallax and declination of the sun and moon produce their several effects on the time and height of the tide, not immediately, but after certain intervals.

Tide, Tide and Half-tide, Tide and Quarter-tide.—In the open sea high and low water succeed each other at intervals of about $6^h 12^m$; such interval is designated "a tide." In channels where a tide-current is formed, when the stream continues to flow up for 3^h after it is high-water, it is said to make "a tide and half-tide"; if it continue to flow during $1^h 30^m$ after high-water, it is said to make "a tide and quarter-tide", and so on.

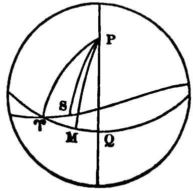
Tide-day, Priming and Lagging.—The tide-day is the interval between two successive arrivals at the same place of the same vertex of the tide-wave. It varies in length as the waves due to the separate action of the moon and sun approach to or recede from coincidence, the resultant maximum being at a point intermediate between them. The lengthening and shortening of the tide-day on its mean is called the *Priming* and *Lagging* of the tide.

Tide, Establishment of the Port.—The sun and moon being in the same relative position, the time of high-water is different for different ports, owing to the inertia of the water and the obstructions it meets with from the friction of the sea-bed, and the narrowness, length, and direction of the channels along which the wave has to travel before reaching the port. It is of great maritime importance to be able to find the time of high-water for harbours and ports, and to this end a standard tide is fixed upon, indicated by a particular relative position of the moon and sun, from which the time of every tide may be deduced. This standard is called the "*Establishment of the Port,*" and is the time of high-water at full and change of the moon at the given port reckoned from apparent noon. It is the actual time of high-water when the moon passes the meridian at the same time as the sun, or the interval between the time of transit of the moon and the time of high-water on full or change days. It may be determined roughly by observation on the day of full or change, and is, in this case, distinguished by Whewell as the "*Vulgar Establishment of the Port*". The "*Corrected Establishment of the Port*" is the interval between the time of the moon's transit and the time of the tide not *on* the day of syzygy, but *corresponding to* the day of syzygy. It may be determined by observing the intervals of the times of the moon's transit and the times of tide every day for a semi-lunation, and taking the mean of these. If we know by how much the transit of the moon to which the tide corresponds is antecedent to the transit next preceding the tide, the corrected establishment may be obtained from one observation of any tide. The establishment for nearly one hundred important stations is registered in the "Nautical Almanac", (1882) pp. 470, 471, under the heading "Time of High-water on the Full and Change of the Moon". Hence may be deduced the time of high-water for any day at the given place. Thu on a particular day the sun and moon pass the meridian of the given place at the same moment, and the interval be observed from this to the high-water next succeeding, we get the apparent time of high-water at the meridional syzygy. On the day following the moon will have moved about 48^m in right ascension more than the sun, and will therefore pass the meridian that much later than on the first day. Now, if the lunitidal interval or period between the moon's transit and the high-water next following be the same for the two days (as it will be nearly if we take into account the action of the moon only), the apparent time of high-water on the second day will evidently be the apparent time of high-water on the first day + the apparent time of the moon's meridian passage on the second day. This is the general principle in the solution of the problem; the details and corrections need not here be noticed. The Establishment of the Port is spoken of by Robertson as "The Time of the Syzygie High-water for the given Port", which may be abbreviated into "*Syzygy Tide*"; similarly it has been called the "*Change Tide*", a term, however, objectionable as expressing either too little or too much; for if the word "change" be extended in meaning to include the time of full as well as of new moon, it ought logically to embrace also the first and third quarters, which in the case before us must be expressly excluded. Raper uses the term "*Tide-hour*", and the German analogue is "*Hafenzeit*", "Harbour-time".

Time.—A definite portion of duration. It is marked in a general manner by the recurrence of striking natural phenomena, such as the alternations of light and darkness, and the succession of the seasons. Thus the two natural measures of time are the *day* or period of the earth's rotation on her axis, and the *year* or period of the earth's revolution in her orbit.—See **Calendar.**

Time, Common and Local.—*Common Time* is reckoned from an epoch initial instant) independent of local situation—such is that known among astronomers as *equinoctial time*, which is the same for all the inhabitants of the earth. *Local time* is reckoned at each particular place from an epoch determined by local convenience, such as the transit of the sun's centre over the meridian of the place; what is called *Greenwich Time* and *Ship Time* are both examples of local time.

Time, Diurnal.—The day depends upon the rotation of the earth on her axis, but this is indicated to a spectator on the surface only by the apparent revolution of the celestial concave in the opposite direction. Diurnal time is, therefore, defined by the motion of some chosen point in the heavens as it appears to revolve from east to west, and is measured by *the angle at the pole of the heavens between the celestial meridian and the hour-circle passing through the point of definition, reckoning westward.* Thus we have *Sidereal Time*, *Apparent Solar Time*, and *Mean Solar Time*, according as the point of definition is the first point of Aries (♈), the actual sun (S), or the mean sun (M). Sidereal Time is measured by the angle at the pole of the heavens between the celestial meridian and the hour-circle passing through the first point of Aries (QP♈); and similarly for Apparent Solar (QPS) and Mean Solar Time (QPM).



Time, Equation of—See under **Equation.**

Time Equivalents.—Two tables are given in the "Nautical Almanac" pp. 478–481; the first for converting intervals of mean solar time into equivalent intervals of sidereal time, the second for converting intervals of sidereal time into equivalent intervals of mean solar time. They are constructed from the formulæ:—

$$M + \cdot 002738\,M = S \ldots (1)$$
$$S - \cdot 002731\,S = M \ldots (2)$$

These tables also serve as Tables of Acceleration and Retardation, by taking the difference between each argument and its equivalent.

Time, Ship.—The mean solar time at the place where a ship happens to be as contrasted with *Greenwich Time*. In east longitude it is evidently before Greenwich Time, in west longitude behind Greenwich Time; every 15° of longitude making a difference of one hour.—See **Longitude in Time.**

Time Azimuth.—An azimuth determined by calculation from these data—the latitude, the declination, and the "hour-angle". An *altitude azimuth* is an azimuth determined by calculation from these data—the latitude, the declination, and the "altitude".—See under **Azimuth.**

Time-balls.—Balls dropped down a staff at observatories, to publish certain preconcerted times, 1 P.M. being that in general use. They are of great use to navigators for determining the error and rate of their chronometers.

Tornado (Sp. and Port. *tornada*).—A storm characterized by its whirling motion.—See under **Storms.**

Torrid Zone (L. *torridus*, "parched").—The zone of the earth included within the tropics or parallels of latitude of about 23° 28′ N. and S. Twice every year the sun is, at noon, close to, if not actually in, the zenith of every place in this zone; consequently the temperature is exceedingly high in this portion of the globe, and hence the name by which it is commonly distinguished.—See **Zones.**

Transit (L. *transitus*, "passage across").—By the "transit of a heavenly body" is commonly understood its passage across the meridian of the observer's station; a "Transit Instrument" is a telescope fixed and moving in the plane of the meridian, and therefore adapted for observing these transits of the heavenly bodies. By the "transits of an inferior planet" (Mercury or Venus) is understood the passage of its dark body across the luminous disc of the sun; and similarly the "Transits of Jupiter's satellites" describes the phenomenon when his satellites are observed as dark spots to pass across the illuminated disc of the planet.

Traverse Sailing.—The case in plane sailing where the ship makes several courses in succession, the track being zigzag, and the directions of its several parts "traversing", or lying more or less athwart each other. For all these actual courses, and distances run on each, a single equivalent imaginary course and distance may be found which the ship would have described had she sailed direct for the place arrived at. Finding this course is called "Working a Traverse". The plane sailing formulæ—

$$\text{Dep.} = \text{dist.} \times \sin \text{course} \ldots (1)$$
$$\text{Diff. lat.} = \text{dist.} \times \cos \text{course} \ldots (2)$$

give for each course and distance the corresponding departure and difference of latitude; and taking the algebraic sum of all the departures and of all the differences of latitude, we get the required course from the formula—

$$\text{Tan course} = \frac{\text{dep.}}{\text{diff. lat.}}$$

and then the distance from either of the formulæ (1) and (2). A table called the *Traverse Table* is used to obviate the necessity of computation.

The following form, illustrated by an example taken from Raper, will be found convenient in working a traverse.

Example.—A ship sails S.W. by S. 24 miles; N.N.W. 57 miles;

S.E. by E. ½ E. 84 miles; and S. 35 miles—find the course and distance made good—

Courses.	Dist.	Diff. Lat.		Dep.	
		N.	S.	E.	W.
Pts. S. 3 W.	24	—	20·0	—	13·3
N. 2 W.	57	52·7	—	—	21·8
S. 5½ E.	84	—	39·6	74·1	—
South.	35	—	35·0	—	—
		52·7	94·6	74·1	35·1
			52·7	35·1	
			41·9	39·0	

Using the Traverse Table, the Diff. lat. 41·9 and Dep. 39·0 are found at 43° against the Dist. 57. Hence, since the ship has made southing and easting on the whole, the resultant course is S. 43° E., and the distance 57 miles. Problem.—*To find the latitude in and longitude in, having given the latitude from, the longitude from, and the several courses and distances run between the two places.* By working a traverse the difference of latitude and departure are obtained. Hence, by applying the difference of latitude to the latitude from, we have the latitude in. The middle latitude is then found, and the solution of the problem completed by the aid of the formula of spherical sailing—

$$\text{Diff. long.} = \text{dep.} \times \text{sec. mid. lat.};$$

the difference of longitude applied to the longitude from, giving the longitude in.—See **Sailings**, and **Plane Sailing**.

Traverse Table.—A table so called from its use in traverse sailing. It contains the true difference of latitude and departure corresponding to every course (at intervals of a quarter-point and also of degrees) from 0 to a right angle, and every distance up to 300 nautical miles (at intervals of one mile). It is constructed by solving a right-angled triangle, of which one angle represents the course and the hypothenuse the distance; by giving these parts different and successive values, the corresponding values of the other two sides are found, which sides represent the true difference of the latitude and the departure. It is evident that the difference of latitude and departure for any course are the departure and difference of latitude for the complement of that course, and hence the table is compactly arranged by interchanging the headings of the columns containing these elements at the top and at the bottom of the page, and using the top reading for courses from 0° to 45°, and the bottom reading for courses from 45° to 90°. This table may be used for a vast number of problems depending for their solution on the relations of the several parts of a right-angled triangle; thus the "correction for run" is generally found by the traverse table.

Triangle, Astronomical or **Instantaneous.**—In Nautical Astronomy the most important spherical triangle is that of which the angular points are the elevated pole of the heavens P, the zenith of the observer Z, and the body observed X; the sides being the polar distance of the body p (the complement of its declination δ), the zenith distance of the body z (the complement of its altitude a), and the zenith-polar arc c which corresponds to the co-latitude of the observer.

This triangle is often called the *Astronomical Triangle*, but I have suggested for it the term *Instantaneous Triangle*. This term prevents all confusion of ideas, and describes its nature with accuracy. The triangle is formed by a transitory combination of elements in three different systems of co-ordinates, two of which are co-axial or co-polar (admitting therefore the coincidence of one of their angles), and two mutually having, each, the pole of its primary situated on a secondary circle of the other (admitting therefore the coincidence of one of their sides). Thus the angle P belongs both to the great-circle system of the co-ordinates Right Ascension and Declination and to the polar system of the co-ordinates Hour-Angle and Polar Distance. Again, the side c belongs both to the great-circle system of the co-ordinates Azimuth and Altitude, and to the celestial measure of the terrestrial co-ordinates longitude and latitude, viz. time and the elevation of the pole. We can imagine the different systems to be fixed for a moment and the points P and Z to retain their relative position. This can only be for a vanishing instant and therefore we call the triangle PZX the *Instantaneous Triangle.*

Triangles, Spherical.—There is no occasion for any verbal rules in navigation, if the formulæ for the solution of spherical triangles are remembered.

(i.) *Right-angled Triangles.* All the formulæ for these triangles are comprised under Napier's two rules. Let A be the right angle; leaving this out, the "circular parts" are b, c, $\frac{\pi}{2} - a$, $\frac{\pi}{2} - B$, $\frac{\pi}{2} - C$. If M be the "middle part," A_1, A_2 the "adjacent parts," and O_1, O_2 the "opposite parts"; then

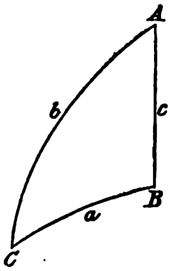
$$\text{Sin } M = \tan A_1 \,.\, \tan A_2$$
$$\text{Sin } M = \cos O_1 \,.\, \cos O_2.$$

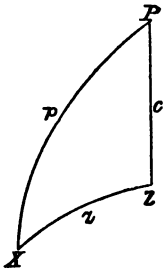
The "middle" part is always selected so that the other two parts are either both "adjacent" or both "opposite". Having written down the equation, make a dash under the part required; its magnitude (whether greater or less than 90°) is determined by placing over the known parts their proper algebraical signs.

(ii.) *Quadrantal Triangles.* The above rules equally apply to these. Let a be the quadrantal side; leaving this out, the "circular parts" are B, C, $\frac{\pi}{2} - A$, $\frac{\pi}{2} - b$, $\frac{\pi}{2} - c$. The magnitude of the required part (whether greater or less than 90°) is determined by placing their proper algebraical signs over the known parts, and also when two angles or sides come together on the same side of the equation a negative sign before them; the three signs thus on one side of the equation must produce the same result (positive or negative) as the sign of the other side.

(iii.) *Oblique-angled Triangles.* There are several forms of the formulæ adapted to the tables available; we give them systematically arranged.

FORMULÆ FOR THE SOLUTION OF THE SPHERICAL TRIANGLE ABC, WHICH CORRESPONDS TO THE INSTANTANEOUS TRIANGLE PZX, AND TO THE GREAT-CIRCLE SAILING TRIANGLE.





	Given.	Required.	FORMULÆ,
			Haversines, etc.
I.	Three sides a, b c,	An angle A	$\text{Hav A} = \text{cosec}\, b \,.\, \text{cosec}\, c \times \sqrt{\text{hav}\ (a + \overline{b-c})\,.\,\text{hav}\ (a - \overline{b-c})}$
II.	(1) Two sides and an opposite angle a, b, B (2) Two angles and an opposite side A, B, b	Opposite angle A Opposite side a	
III.	Two sides and included angle c, A, b	Remaining side a	$\left\{\begin{array}{l}\text{Vers}\ a = \text{vers}\ (b - c) + \text{vers}\ \theta \\ \text{where Hav}\ \theta = \sin b \,.\, \sin c \,.\, \text{hav A}\end{array}\right\}$
IV.	Two sides and included angle c, A, b	Remaining angles B and C	
V.	Two angles and included side C, a, B	Remaining sides b and c	

FOR TABLES USED.		
	Versines, etc.	Sines, Cosines, etc.
I.		$\text{Sin}^2\frac{A}{2}=\frac{\sin(S-b)\,.\,\sin(S-c)}{\sin b\,.\,\sin c}$ *or* $\text{Cos}^2\frac{A}{2}=\frac{\sin S\,.\,\sin(S-a)}{\sin b\,.\,\sin c}$ where $S=\frac{a+b+c}{2}$
II.		(1) $\text{Sin}\ A=\sin B\,.\,\frac{\sin a}{\sin b}$ (2) $\text{Sin}\ a=\sin b\,.\,\frac{\sin A}{\sin B}$
III.	$\text{Vers}\ a=\text{vers}\,(b-c)+N$ where $N=2\sin b\,.\,\sin c\,.\,\sin^2\frac{A}{2}$	$\text{Sin}\,\frac{a}{2}=\sin\left(\frac{b+c}{2}+\theta\right).\sin\left(\frac{b+c}{2}-\theta\right)$ where $\sin\theta=\sqrt{\sin b\,.\,\sin c\,.\,\cos^2\frac{A}{}}$
IV.	. . . .	First find a by III. and use it as one of the data in II. (1) *or* $\text{Tan}\ \frac{B-C}{2}=\sin\frac{b-c}{2}\,.\,\text{cosec}\,\frac{b+c}{2}\,.\,\cot\frac{A}{2}$ $\text{Tan}\ \frac{B+C}{2}=\cos\frac{b-c}{2}\,.\,\sec\frac{b+c}{2}\,.\,\cot\frac{A}{2}$ Whence $B=\frac{B+C}{2}+\frac{B-C}{2}$ $C=\frac{B+C}{2}-\frac{B-C}{2}$
V.		$\text{Tan}\ \frac{b-c}{2}=\sin\frac{B-C}{2}\,.\,\text{cosec}\,\frac{B+C}{2}\,.\,\tan\frac{a}{2}$ $\text{Tan}\ \frac{b+c}{2}=\cos\frac{B-C}{2}\,.\,\sec\frac{B+C}{2}\,.\,\tan\frac{a}{2}$ Whence $b=\frac{b+c}{2}+\frac{b-c}{2}$ $c=\frac{b+c}{2}-\frac{b-c}{2}$

Triangulum Australe (L. "The Southern Triangle").—A constellation lying about half-way between Scorpio and the south pole. α *Trianguli Australis*, mag. 2; 1882, R.A. $16^{h}\ 36^{m}$, Dec. − 68° 48′.

Tropics (Gk. *τὰ τροπικὰ*, from *τρέπω*, "I turn").—The two parallels, one on the north and the other on the south side of the equator, whose latitude is equal to the sun's maximum declination (about 23° 28′ N. and S.). The term was originally applied to the celestial parallels of declination of about 23° 28′ N. and S. Their positions go through small changes of long period. When the sun, after coming north, has attained his greatest northern declination, he "turns" towards the equinoctial again; and when, after going south, he has attained his greatest southern declination, he "turns" towards the equinoctial again. Hence the name *Tropics;* and as at the time this nomenclature was adopted the sun attained his greatest northern declination in the constellation of Cancer, and his greatest southern declination in the constellation of Capricorn, the Northern and Southern Tropics were respectively called the *Tropic of Cancer* and the *Tropic of Capricorn*. The tropics mark out the limits of the torrid zone, or that portion of the earth's surface over which the sun can be vertical during the year, dividing this belt from the temperate zones.

True.—An adjective used to qualify elements when referred to a common standard for comparison. Thus the centre of the earth is the imaginary common standing-ground whence the heavens are supposed to be viewed through a uniform medium, and to which all observations of the heavenly bodies, made at different parts of the earth's surface through the atmosphere, are reduced and referred for comparison and computation. Hence the "True Place" of a heavenly body is its projection on the celestial concave, the body being supposed to be viewed from the centre of the earth through a uniform medium; distinguished from the "Apparent Place." The epithet *true*, therefore, does not indicate the actual place of the body in space, but a standard position of its projection on the celestial concave, to which all other positions that its projection assumes, when seen from different spots on the earth's surface, may be referred and reduced. Similarly we have the "True Distance" of two heavenly bodies, distinguished from their "Apparent Distance." Again, the normal to the earth's surface is the direction to which we refer angles of elevation, and hence the point in which this line meets the celestial concave is designated as the "True Zenith", as opposed to the "Reduced Zenith"; and thus also the "True Latitude" of an observer is distinguished from the "Reduced Latitude". In like manner the meridian, being the common line to which we refer directions on the earth's surface, the "True Bearing" of an object, or the "True Course" of a ship, is an angle reckoned from the meridian, distinguished from the "Compass Bearing" and the "Compass Course".

Twilight (Sax. *tweon-leoht*, "doubtful light").—The atmosphere, by refracting the sun's rays, causes that body to be seen by a spectator on the earth's surface while yet in reality below his horizon. But before the sun thus becomes visible, rays of light illuminate the atmosphere, which reflects and scatters them in all directions, and the result is that faint "doubtful" light which precedes the rising of the sun and follows its setting, called twilight. Twilight begins and ends when the sun is about 18° below the horizon; and its duration, therefore varies with the latitude, for the time which is required for the sun to rise through 18° vertically depends upon the inclination of its diurnal path to the horizon of the place, and is greater as this inclination is less, *i.e.* the higher the latitude. The condition of twilight lasting all night is, that the greatest depression of the sun below the horizon shall not be more than 18°, or declination of sun + latitude of place must not be less than 72°. Twilight is the best time for observing altitudes of stars at sea, for then the horizon is in general clearly visible and distinctly marked.—See **Illumination.**

Typhoon (Gk. *τυφὼς*, "a violent wind", which whirls up clouds of dust or mist; from τῦφος, "smoke," "cloud").—This word is now specially applied to the revolving storms of the Chinese seas.—See under **Storms.**

U.

u.—Of the letters used to register the state of the weather in the log-book, **u** indicates "*Ugly threatening appearance of the weather*".

Uarnography (Gk. οὐρανὸς, "heaven"; γράφειν, "to grave", "describe"). —The science which deals with the mapping down of the celestial concave, representing the relative positions of the stars on a globe or on charts. Compare the terms *geography, hydrography.*—See **Stars.**

Uranus (Gk. οὐρανὸς, "heaven").—The name now given to the planet revolving round the sun next after Saturn. It has also been called *Herschel* and *Georgium Sidus.*

Ursa Major (L. "The Greater Bear").—The most brilliant constellation of the northern hemisphere, consisting of seven principal stars. By the common people of most countries this group is called "*The Waggon*", and sometimes "*The Plough*"; in England it has been known as "*Charles's Wain*". It is one of those constellations which, like Ursa Minor, Cassiopeia, and Draco, in our latitude (51° N.) never set, and therefore it can always be seen by us on a clear night. The four stars, α, β, γ, δ, form a trapezium, the longest side of which contains α and δ, γ being in the opposite angle to α; next to δ is affixed a scalene triangle, formed by the stars ε, ζ, η, which represent the tail of the Bear. The two stars β and α are called "The Pointers", as they point to the pole star; the pole star being thus found, the position of the pole itself may be roughly determined with the aid of the other star ε. [See **Polaris**]. The following are the right ascensions and declinations of these stars, together with their proper names:—

		Mag.	R.A. 1882.	Dec. +.
α	*Ursæ Majoris*, or *Dubhe*	1.2 (var.)	10h 56m	62° 23′.
β	„ „ *Merak*	2.3	10h 54m	57° 2′.
γ	„ „ *Megrez*	2.3	11h 48m	54° 21′.
δ	„ „ *Phegda*	2.3	12h 10m	57° 43′.
ε	„ „ *Alioth*	1.2 (var.)	12h 49m	56° 38′.
ζ	„ „ *Mirzar*	2.3	13h 20m	55° 34′.
η	„ „ *Benetnasch*	2.3	13h 43m	49° 54′.

Ursa Minor (L. "The Lesser Bear").—A constellation notable from its containing, at the end of the tail, the Pole Star. In form it is something like the Greater Bear, the trapezium of the one being adjacent to the triangle of the other. *α Ursæ Minoris* or *Polaris Stella*, mag. 2; 1882, R.A. 1h 15m, Dec. + 88° 41′.—See **Polaris**.

V.

v.—Of the letters used to register the state of the weather in the log-book, v indicates "*Visibility of Distant Objects, whether the sky be cloudy or not*".

Vane (Sax. *Fana*, Dut. *Vaan*).—

1. A contrivance for showing the direction of the wind.
2. A sight placed on instruments for taking observations of altitudes and distances, marking the direction from the eye to the object.

Variation of the Compass (L. *variatio*, "a changing").—The angle which the position of the magnetic needle, undisturbed by local attraction or ship's influence, makes with the geographical meridian of the station. This term should be exclusively appropriated to the error which arises from the magnetic poles of the earth not coinciding with the poles of rotation.—See under **Magnetic Needle**, and **Compass**.

Vega.—The proper name of the bright star *α Lyræ*.—See **Lyra**.

Venus (named after the Roman goddess of beauty).—The most beautiful of the planets. It is one of the inferior planets, its orbit being next to that of the earth. In actual size Venus is a little less than the earth, but, owing to its propinquity to us, its apparent diameter is sometimes as much as 62″. In consequence of its nearness to the sun it shines with a very bright light, but as seen from the earth this brightness varies in a remarkable manner. The change is due partly to the change of apparent magnitude of the disc from change of distance, partly to the varying ratio of the visible illuminated area to its whole disc, for it presents phases like the moon. The light is of a bluish tinge. The transits of Venus across the sun's disc are important astronomical phenomena, as they afford the best means of determining the sun's parallax and consequently the dimensions of the planetary system. To the navigator the body is chiefly important as serving, in a pre-eminent manner, the ordinary purposes of bright stars, such as determining the latitude, and by its lunar distances furnishing the means of obtaining the longitude. It deserves especial notice, as it can often be observed during the daytime; it was called by the Greeks *Hesperus*, the "evening", and *Phosphorus*, the "morning" star. Symbol ♀.—See **Planets.**

Vernal Equinox (L. *vernālis* "pertaining to the spring", *ver*).—Relatively to the northern hemisphere, the Vernal Equinox is that date when the sun crosses from the south to the north of the equinoctial; about March 20th.—See **Equinoxes.**

Vernal Equinoctial Point.—Relatively to the northern hemisphere, the Vernal Equinoctial Point is the intersection of the ecliptic by the equinoctial, where the sun crosses from the south to the north of the equinoctial. It is more generally called "*The First Point of Aries*".—See **Equinoctial Points.**

Vernier (named after the inventor, Pierre Vernier, 1631).—An index for reading off the graduated scale or limb of an instrument, by which aliquot parts of the smallest spaces into which the scale or limb is divided are measured. It consists of a piece similar to the scale or arc to be read, along which it slides. The length of this piece is made such as to include exactly some particular number of divisions of the scale; it is then divided into a number of equal parts, differing by one from the number of divisions in that part of the scale with which it coincides. There are hence two forms of vernier, according as the number of divisions in it is *one less* (fig. 1) or *one greater* (fig. 2) than in the corresponding length of the scale. Now, if the two extremities of the vernier be made to coincide with certain lines of graduation of the scale, then it is evident that none of the intermediate lines of the vernier will coincide with those of the scale. The first division of the vernier will exceed or fall short of the first of the intermediate divisions of the scale by a certain space, the second will exceed or fall short by twice this space, the third by three times this space, and so on to the last, which will exceed or fall short by a whole division. Hence the space by which the first division of the vernier exceeds or falls short of that on the scale will be that fraction of a division of the scale whose numerator is unity, and denominator the number of divisions in the vernier. If, therefore, from the position in which the extremity of the vernier coincides with a line of graduation of the scale, we retreat or push forward the vernier through the above space, its next line of graduation will coincide with the next line on the scale; if we retreat or push it through another such space, the next line will coincide, and so on. Conversely, if we see any line of the vernier coinciding with one of the scale, we know, by counting the number of lines from the end, how many spaces it has been moved from its first position, or tell this by inspection if the extreme line of the vernier is marked zero and the rest one, two, three, etc. Hence, if the index-point or zero-line do not exactly coincide with a line of graduation of the scale, we have only to carry the eye along the vernier till we mark some lines

Fig. 1.

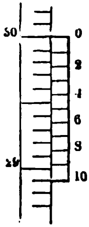
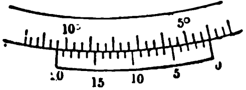


Fig. 2.



of division which are coincident; the number of this division on the vernier will give that fraction of a division of the scale by which the zero-point is distant from the preceding line of graduation on the scale.

Let l be the length of the vernier, and n the number of divisions it contains, each of which is therefore $\frac{l}{n}$ in length.

When the first kind of vernier is used, the length l of the limb of the instrument is divided into $n + 1$ parts, each of which will be $\frac{l}{n+1}$ in length. The difference therefore between the length of the divisions on vernier and on limb is $\frac{l}{n} - \frac{l}{n+1} = \frac{l}{n(n+1)}$.

When the second kind of vernier is used, the length l of the limb is divided into $n - 1$ parts, each of which will be $\frac{l}{n-1}$ in length. The difference therefore between the length of the divisions on limb and on vernier is $\frac{l}{n-1} - \frac{l}{n} = \frac{l}{(n-1)n}$.

The first kind is the form originally proposed by the inventor; it has the advantage of the greater size and consequent clearness of its divisions, but it has to be numbered backwards or in a direction contrary to that of the limb of the instrument.

It would be convenient to have distinctive names for the two kinds of verniers. From their size relatively to a portion of the limb containing the same number of divisions, they might be distinguished as the *Greater* and *Less Verniers*. From the direction of their graduation they might respectively be named the *Reverse* and *Direct Verniers*. From their position relatively to the zero when advanced along the limb, Mr. Escott proposes the names *Following* and *Preceding Verniers*. He also describes the minuteness of the possible reading by the term *Degree of Accuracy*.

A vernier of the first kind is that which is generally attached to the scale of an ordinary barometer. The barometer scale (fig. 1) is divided into inches and tenths; and the vernier, being in length $\frac{11}{10}$ of an inch and divided into ten equal parts, measures hundredths of an inch.

The vernier used for scientific barometers is of the second kind, and in general twenty-five vernier spaces equal twenty-four of the scale spaces, which are each half a tenth, or five hundredths of an inch; therefore the difference between one of the vernier and one of the scale is two tenths of a hundred, or two thousandths of an inch. Thus, in the marine barometer, reading ·002 of an inch, the short divisions on the scale correspond to ·05 of an inch, the long divisions on the vernier to ·01, and its short divisions to ·002 of an inch.

The *limb of the sextant*, and of similar astronomical instruments, is read by a vernier of the second kind (fig. 2). Suppose the limb to be cut to a third part of a degree, or 20′, then, if the length of the vernier be equal to 19 of these divisions, and is divided into 20 equal parts, by its means we are enabled to read off $\frac{1}{20}$ of each division of the limb, or to measure angles truly to 1′. This is the simple form of the vernier. In instruments for measuring angles it is convenient that the vernier should be divided into 60 equal parts, so as to enable us to read off to the same number of *seconds* as the limb is graduated in to *minutes*. This could be effected by making it in length equal to 59 divisions of the limb; but then, if the limb is highly graduated, the cutting would be minute, and the reading by the vernier not clearly distinguishable. The difficulty is obviated as follows:—The vernier is made in length equal to $\{(n \times 60) - 1\}$ divisions of the limb (where n is an integer), but still dividing it into 60 equal parts instead of $(n \times 60)$. Thus, let the limb be graduated to 10′; take $n = 2$, then the length of the vernier will be 119 of the divisions of the limb (10′ each). Now, if the vernier were divided into 120 (2×60) equal parts, it would enable us to read to $\frac{1}{120}$ of 10′; but this is unnecessary and inconvenient. It is therefore divided into 60 equal parts only, and enables us to read to $\frac{1}{60}$ of 10′, or to 10″.

Vertical Circles (L. *vertex*, "the top" or "crown", from *verto*, "to turn ").—Great circles of the celestial concave which pass through the vertex of the visible hemisphere, and are therefore perpendicular to the horizon. They are also called "*Circles of Altitude*", because altitudes are measured on them, and "*Circles of Azimuth*", as marking out all points that have the same azimuth.—See **Co-ordinates for the Surface of a Sphere.**

Vertices of Great Circle.—The two points of highest latitude N. and S. on the great circle passing through two given places, such places not being both on the same meridian, or on the equator. Each vertex is 90° from the points where the great circle crosses the equator.

Virgo, Constellation of (L. "The Virgin").—The sixth constellation of the ancient zodiac, lying between Leo and Libra. It contains a very brilliant star, *α Virginis*, called also *Spica*, which may be found by drawing a line from *Dubhe* through *Cor Caroli*, and producing it to a little more than the same distance; or it may be recognized as forming an equilateral triangle with *Arcturus* and *β Leonis*, of which it is the southern angle. Mag. 1; 1882, R.A. $13^h\ 19^m$, Dec. — 10° 33′.

Virgo, Sign of.—The sixth sign of the ecliptic, including from 150° to 180° of longitude. Owing to the precession of the equinoxes, the *constellation* Virgo is no longer in the *sign* of this name, the constellation Leo having taken its place. The sun is in Virgo from about August 23rd to about September 23rd. Symbol ♍.

Visible Horizon.—(1) The circle of the celestial concave which divides the visible from the invisible portion of the heavens. (2) The circle of the terrestrial sphere which divides the visible from the invisible portion of its surface.—See **Horizon.**

Vulgar Establishment of the Port.—The establishment of the port—*i.e.* the time of high water at the full and change of the moon at the given port—determined roughly by observation on the day of full or change.—See under **Tide.**

W.

w.—Of the letters used to register the state of the weather in the log-book, **w** indicates " *Wet Dew* ".

Wake.—The wake of a ship as she moves through the sea is the transient impression she leaves on the surface caused by the meeting again of the divided waters. It indicates her actual path through the water, which in general is not in the same line with that of her keel. The angle between the two lines is the leeway.

Wave (Sax. *wag.*)—The oscillation caused in a fluid by a motion perpendicular to its surface. The alternate rising and falling causes the appearance of a transfer of the body of the fluid in the direction in which the wave is propagated, though no such transfer actually takes place. The action may be illustrated by the fluttering of a flag, the shaking of a sail, or the appearance of a field of standing corn when a breeze passes over it.

Wave, Height of.—The perpendicular rise of the vertex of the wave or " crest " above the lowest part of its depression or " hollow ".

Wave, Length of.—The horizontal distance between two adjacent crests, or two adjacent hollows.

Wave, Velocity of.—The rate at which the crest moves forward; it is the length of the wave divided by the interval any phase takes to pass through the length.

Weather-glass.—This term is usually applied to the barometer, which by its rising and falling indicates in a general way the impending weather. But a perfect weather-glass properly consists of—a *Barometer*, which shows changes in the pressure or tension of the atmosphere; a *Thermometer*, which shows changes in the temperature; and a *Hygrometer*, which shows changes in the moisture of the air. By combining these several particulars, the state of the air is known, and hence is inferred coming weather. The following are the fundamental rules for the indications of the weather-glass in any latitude. Rise of barometer for cold, dry, or less wind (except wet from cooler side); fall of barometer for warm, wet, or more wind (except wet from cooler side). Thus, in northern latitudes, if the barometer has been about its ordinary height, say nearly thirty inches at the sea-level, and is steady, or rising, while the thermometer falls, and dampness becomes less, north-westerly, northerly, or north-easterly wind—or less wind—less rain or snow—may be expected. On the contrary, if a fall takes place, with a rising thermometer and increased dampness, wind and rain may be expected from the south-eastward, southward, or south-westward. Exceptions.—When a northerly wind with wet (rain, hail, or snow) is impending, the barometer often rises on account of the *direction* of the coming wind alone. For more particular rules, with their exceptions, the reader is referred to Rear-Admiral Fitzroy's "Barometer Manual", issued by the Board of Trade.

Weather Notation.—To register the state of the weather the annexed system of letters was devised by Sir Francis Beaufort, and used by him in his log of H.M.S. *Woolwich*, 1805. It has been adopted in the Royal Navy by Admiralty order, dated December 28, 1838:—

b denotes Blue Sky—whether with clear or hazy atmosphere.
c „ Cloudy—*i.e.* Detached opening clouds.
d „ Drizzling Rain.
f „ Fog; f̣ Thick Fog.
g „ Gloomy Dark Weather.

h	denotes	Hail.
l	„	Lightning.
m	„	Misty or Hazy—so as to interrupt the view.
o	„	Overcast—*i.e.* The whole sky covered with one impervious cloud.
p	„	Passing Showers.
q	„	Squally.
r	„	Rain—*i.e.* Continuous Rain.
s	„	Snow.
t	„	Thunder.
u	„	Ugly threatening appearance of the Weather.
v	„	Visibility of Distant Objects—whether the sky be cloudy or not.
w	„	Wet Dew.
•		Under any letter denotes an Extraordinary Degree.—Instead of this mark, some meteorologists are accustomed to repeat a letter to augment its signification. Thus, **ff**, very foggy; **rr**, heavy rain; **rrr**, heavy and continued rain.

By the combination of these letters all the ordinary phenomena of the weather may be recorded with certainty and brevity. Examples—**bcm**, Blue sky, with detached opening clouds, but hazy round the horizon; **gṿ**, Gloomy dark weather, but distant objects *remarkably* visible; **q̣pdlṭ**, very hard squalls, and showers of drizzle, accompanied by lightning, with *very* heavy thunder.—See **Wind, Force of.**

West Point of the Horizon.—The west is the cardinal point on that side of the horizon where the heavenly bodies set. The *East* and *West Points* are the points in which the prime vertical intersects the horizon, the equinoctial also passing through them, and they are the origins from which amplitudes are reckoned. They are the poles of the celestial meridian.

Westing.—The distance, expressed in nautical miles, a ship makes good in a west direction; it is her departure when sailing westward. Opposed to *Easting*.

Wind, Aberration and Acceleration of.—The change in the apparent direction of the wind, in consequence of the motion of the observer, we call *the aberration of the wind*. The change in the apparent rate of the wind, in consequence of the motion of the observer, we call *the acceleration of the wind;* it is negative, and appears as *retardation* when the directions are not opposed.

For explanation of the terms, see under **Aberration** and **Acceleration.**

Example—A north wind is blowing at the rate of 10 knots an hour, and two steamers cross, one on a west and the other on an east course, the former going 12 and the latter 8 knots an hour. They would apparently experience, respectively, a N.W½.W. and a N.E.½N. wind, a difference of 8 points. And so for the rates: the former would experience a wind blowing 16, and the latter a wind blowing 13 knots.

Every seaman is familiar with the phenomena, and practically takes them into account for his own immediate requirements; but the subject has not yet been fully recognized in a systematic manner for the general interests of nautical meteorology. Experience teaches the seaman to estimate the true direction and real force of the wind by the indications of the tops of the waves or of the lowest clouds, which he instinctively takes into account; also from the known behaviour of his ship under given conditions.

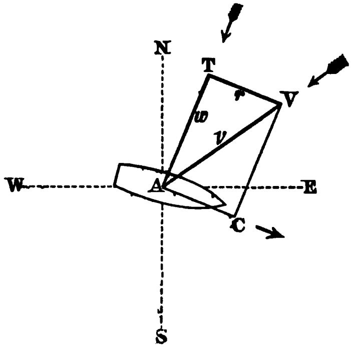
The following exact method of deducing the true direction and force of the wind, from its apparent direction and force, combined with the course and speed of the ship, will be of interest to the scientific keeper of a meteorological log. Our data are:

The compass course of the ship through the water, NAC;

The rate of the ship AC $(= r)$;

The apparent compass direction of the wind, as indicated by a vane, VAN;

The apparent velocity of the wind, estimated by an anemometer, VA (= v).



We have to find:

The true direction of the wind TAN; and

The true velocity of the wind TA (= w).

Complete the parallelogram ACVT; then knowing the angle NAC, we may, for simplicity, refer all the directions to AC. In the triangle TVA, the angle V and the two sides r and v are known; to determine W and w:

(I.) To find the *aberration* TAV (= A), and thence the *true direction* of the wind TAN;

$$\text{Tan } \tfrac{1}{2}(T - A) = \frac{v - r}{v + r} \cdot \cot \frac{V}{2}$$

$$\tfrac{1}{2}(T + A) = \tfrac{1}{2}(180^\circ - V)$$

$$\text{Hence } A = \tfrac{1}{2}(T + A) - \tfrac{1}{2}(T - A)$$

And True Direction = Apparent Direction − Aberration.

(II.) To find the *true velocity* of the wind TA = (w)

$$\frac{w}{r} = \frac{\sin V}{\sin A} \text{ or } \frac{w}{v} = \frac{\sin V}{\sin T}$$

The *acceleration* (a) = $v - w$.

Wind, Direction of.—The direction of the wind is named after the point of the compass *from* which it blows.—See under **Direction.**

Wind, Force of.—To register the force of the wind the annexed system of figures was devised by Sir Francis Beaufort, and used by him in his log of H.M.S. *Woolwich*, in 1805. It has been adopted in all her Majesty's ships by Admiralty order, dated December 28, 1838.—See **Weather Notation.**

0	denotes	Calm.		
1	„	Light Air.........	just sufficient to give	Steerage way.
2	„	Light Breeze ...	with which a well-conditioned man-of-war, under all sail, and clean full, would go in smooth water, from	1 to 2 knots.
3	„	Gentle Breeze ...		3 to 4 knots.
4	„	Moderate Breeze		5 to 6 knots.
5	„	Fresh Breeze ...	in which the same ship could just carry close-hauled	Royals, etc.
6	„	Strong Breeze ...		Single-reefs and top-gallant sails.
7	„	Moderate Gale...		Double-reefs, jib, etc.
8	„	Fresh Gale		Triple-reefs, courses, etc.
9	„	Strong Gale......		Close-reefs & courses.
10	„	Whole Gale	with which she could only bear	Close-reefed main topsail and reefed foresail.
11	„	Storm	with which she would be reduced to	Storm staysails.
12	„	Hurricane.........	to which she could show	No canvas.

Winds, Trade.—Winds which, blowing perpetually in the same constant direction (north-easterly in the northern, and south-easterly in the southern hemisphere), are subservient in a peculiar manner to the purposes of navigation and trade. These important currents of the atmosphere are the result of a combination of two causes. First, the unequal exposure of the earth's surface to the sun's rays causes the air over the equatorial regions to be unduly heated and rarified; it consequently ascends, while the cooler and denser air from the regions more polar rushes in along the earth's surface to supply its place, the heated air being carried along the higher strata towards the poles. Hence, if unmodified by any other cause, two counter-currents in each hemisphere would be formed in the direction of the meridian. But, secondly, the equatorial portion of the earth's surface has the greatest velocity of rotation, and all other parts less in the ratio of the radii of the parallels of latitude to which they correspond. A portion of air, therefore, coming from the polar to the equatorial regions revolves more slowly than the parts of the earth over which it in succession arrives, and it will consequently lag behind and drag upon the surface in a direction contrary to the earth's rotation—*i.e.* from east to west. Thus the currents which, but for the earth's rotation, would be simply northerly and southerly winds, acquire from this cause a *relative* direction towards the west, and assume the character of permanent north-easterly and south-easterly winds. As these two currents approach the equator, their easterly tendency is generally diminished by the friction of the earth, and when they meet at the equator their northerly and southerly direction mutually destroy each other; hence an equatorial belt of comparative calm which separates the belts of the north-easterly and south-easterly trades. The trade-winds are modified in direction and intensity by the neighbourhood of continents, and vary in position with the seasons.

Windward Sailing.—When a ship has a foul wind she has to work to windward, making her destination by means of tacking. Windward sailing is therefore a case of *traverse sailing*, in which the characteristic inquiry is, what is the most advantageous time for tacking? Supposing the wind to remain constant in direction, the general principle is to endeavour to near the destination from instant to instant. In order to do this the destination must always be kept in the wind's eye, a condition which would necessitate continual tacking. This being practically impossible, the question resolves itself into determining the practical limits for the application of the theoretical principle. A ship nears the destination fastest on that tack on which she looks up best for it; she should therefore stand on on each tack as long as this continues to be the case, and then go about. The destination is above supposed to be fixed, as in the case of a port; but it may be another ship in motion, as in *chasing*. Chasing is a subject belonging to sea tactics, and was of great importance before the introduction of steam. In windward sailing, the position of the great circle is of the greatest importance. A wind which appears to be directly ahead when viewed in connection with the rhumb, may not be so with reference to the great circle; and as the great circle is the shortest path of the ship to her destination, that tack will be chosen that lies nearest to it, and persisted in as long as, judged by the same standard, it continues to be the most favourable. In short, in windward sailing tacking ought to have reference to the great circle, and not to the rhumb.—See **Sailings**.

Winter Solstice.—Relatively to the northern hemisphere, the winter solstice is the period of the year when the sun attains his greatest southern declination—about December 21st.—See **Solstices**.

Y.

Year.—Generally—The period in which the earth makes a revolution in her orbit round the sun, as indicated by the corresponding apparent revolution of the sun in the ecliptic. But more particularly—Some point must be taken to mark its commencement and period, which we call the "point of definition", and the choice (as this point may be fixed or have a proper motion of its own) gives rise to a distinction of several kinds of years which differ from each other slightly in length. (1) If a *fixed star* be taken as the point of definition, we have the *Sidereal Year*. (2) If the *first point of Aries* (which has a slow retrograde proper motion of about

50·22″ annually) be taken as the point of definition, we have the *Solar, Equinoctial*, or *Tropical Year*. (3) There is also what is called the *Anomalistic Year*, which is the period between two successive returns of the earth to the perihelion of her orbit, a point which has a direct proper motion of 11·25″ annually. The anomaly (Gk. ἀν, "not", ὁμαλὸς, "even"; "irregularity") of a planet is its angular distance from the perihelion of its elliptic orbit as seen from the sun, and it is so named because the angular motion about the sun in the focus is *not uniform*. The relative length of the three years will be—

Sidereal : Tropical : Anomalistic
= 360° : 360° − 50·22″ : 360° + 11·25″

The tropical year having been found, we have the following values, in mean solar time,

Sidereal year = 365·256374 days = $365^d\ 6^h\ 9^m\ 11^s$;
Tropical year = 365·242216 days = $365^d\ 5^h\ 48^m\ 48^s$;
Anomalistic year = 365·259544 days = $365^d\ 6^h\ 13^m\ 45^s$.

Year, Sidereal (L. *sidus*, "a star").—The period in which the earth makes a revolution in her orbit with reference to the fixed stars. Substituting the sun's apparent motion in the ecliptic, the sidereal year is the interval between his leaving a fixed point in the celestial concave, such as a fixed star, and returning to that point again. The sidereal year consists of $365^d\ 6^h\ 9^m\ 11^s$, reckoned in mean solar time, and of $366^d\ 6^h\ 9^m\ 11^s$, reckoned in sidereal time. The reason of this difference is that the sun's apparent annual motion among the stars is in a direction contrary to the apparent diurnal motion of both sun and stars. The effect is the same as if the sun lagged behind the stars in his daily course, and when this has gone on for a whole year, he will have fallen behind them by a whole circumference of the heavens—*i.e.* in a year the sun will have made fewer diurnal revolutions by one than the stars. The same interval of time, therefore, that is measured by $366^d\ 6^h$, etc., of sidereal time will be measured by $365^d\ 6^h$, etc., of mean solar time.

Year, Solar, Tropical, or Equinoctial.—The interval in which the sun in his apparent motion makes a complete revolution of the ecliptic, thus describing 360° of longitude. The first point of Aries being the origin, the solar year is defined to be the period between the sun leaving the first point of Aries and returning to it again. This year is the period of the revolution of the seasons, which are determined by the apparent passage of the sun across the equinoctial, and his alternate stay in the northern and southern hemispheres, where the turning-points in his course are the tropics. The period is thus called the *Tropical Year* with reference to the solstices when the sun describes his diurnal circle of the *tropics;* it is also called the *Equinoctial Year* with reference to the *equinoxes* when the sun crosses the line; it is likewise called the *Solar Year* with reference to the *sun's* apparent motion in the ecliptic. In the *sidereal period*, or year, the earth makes a complete revolution of the heavens, and the sun appears to do so, but not so in the tropical year. The vernal equinoctial point, owing to the slow conical motion of the earth's axis, retreats on the ecliptic and meets the advancing sun somewhat before the whole sidereal circuit is completed. The precession for the year 1882 is 50·2597″, and this arc the sun describes in 23·9^s. By so much shorter then is this solar year than the sidereal period. The tropical year is a compound phenomenon depending chiefly and directly on the annual revolution of the earth round the sun, but subordinately also, and indirectly, on its rotation on its own axis, which occasions the precession of the equinoxes. The tropical years vary in length owing to the motion of the first points of Aries not being uniform, and the sun's apparent motion being subject to irregularities.

Year, Mean Solar, or Mean Tropical.—The solar or tropical year has been defined as the interval which elapses between the sun, in his apparent motion in the ecliptic, leaving the first point of Aries and returning to it again. But the motion of the first point of Aries is not uniform, and the sun's motion in the ecliptic is from year to year subject to irregularities;

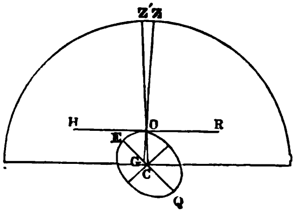
hence solar years vary in length. An average of a long succession of solar years gives an approximation to the mean solar year. By a comparison of observations it was found that the sun had described $36000° 45' 45''$ of longitude in 36245 days mean time. Taking our average from this lapse of time, the length of the mean solar year $= \frac{360° \times 36,245^{d}}{36000° 45' 45''} = 365^{d}\ 5^{h}\ 48^{m}\ 51{\cdot}6^{s}$ The latest value obtained is about $365^{d}\ 5^{h}\ 48^{m}\ 48^{s}$.

Year, Civil.—The year used for practical purposes should consist of an integral number of days, which the mean solar year does not. As an equivalent to a series of actual mean solar years, a succession of civil years, some consisting of 365 and others of 366 days each, has been established by the regulations of the calendar: the former are called *Common Years*, the latter *Bissextile* or *Leap Years*.—See **Calendar.**

Z.

z.—The letter **z** is sometimes used in log-books to denote *haze*.

Zenith (Arabic).—The superior pole of the celestial horizon. It is the point of the heavens vertically over a spectator's head—*i.e.* the point in which the normal to the earth's surface at the station of the spectator, produced into space, meets the celestial concave. If the earth be considered a sphere, the normal will always pass through its centre, but on the spheroid this is not the case. When, therefore, we take into account that the earth is in reality an oblate spheriod, we must distinguish between the true and the reduced zenith. The *True Zenith* is the point in which



the normal to the earth's surface at the station of the spectator, produced into space, meets the celestial concave; the *Reduced Zenith* is the point in which the line joining the earth's centre and the station of the spectator, produced into space, meets the celestial concave. Thus let O be the station of the observer on the earth's surface, HR his horizon; OG the normal at O, and OC the semi-diameter passing through O, meeting the plane of the equator EQ respectively in G and C; let GO produced meet the celestial concave in Z, and CO produced meet it in Z′. Then Z is the true, and Z′ the reduced zenith of the station O. They coincide at the poles, and on the equator. The point diametrically opposite to the zenith is the nadir, which is the inferior pole of the horizon.—See **Zenith and Nadir.**

Zenith and Nadir (Arabic).—The poles of the celestial horizon. The *Zenith* is the superior pole, or the point of the heavens vertically over a spectator's head; the *Nadir* is the inferior pole, or the point of the heavens vertically under the spectator's feet.

Zenith Distance.—The angular distance of a point in the celestial concave from the zenith. It is the complement of its altitude above the horizon.

Zenith Parallels.—A name proposed for the circles of the celestial sphere corresponding to the *parallels of position* on the terrestrial sphere. —See **Position, Parallels of.**

Zenith Sector.—A shore instrument for measuring with great accuracy the zenith distances of stars which pass the meridian near the zenith. Bradley constructed one when discovering the aberration of light and the nutation of the earth's axis. The zenith sector is applied in trigonometrical surveys for determining the difference of latitude of two stations.

Zenith-polar Arc.—In the Instantaneous Triangle, the side joining the zenith and the pole; it is the celestial arc corresponding to the co-latitude on the terrestrial sphere.

Zero (It.).—The term generally used to indicate the point of a scale from which the graduations commence. Thus,—the zero on the limb of a sextant is where the index should point when the index-mirror and horizon-mirror are parallel; the zero on the scale of a Reáumur and of a Centigrade thermometer is the freezing point of water; the zero of Fahrenheit's scale is obtained by the temperature produced from a mixture of salt and snow. The readings of a scale are reckoned plus in one direction from the zero point, and minus in the contrary direction.

Zodiac (Gk. ὁ ζωδιακὸς, from ζώδιον, the diminutive of ζῶον, "an animal").—That region of the heavens within which the apparent motions of the sun, moon, and all the most conspicuous of the planets—those known to the ancients—are confined. By continued observation we may map down the apparent paths of these several bodies, just as the course of a ship is marked out by pricking off its place from day to day. It was thus found that the apparent path of the sun is a great circle inclined to the equinoctial at an angle of about 23° 28′, to which the name "ecliptic" was given. Again, the apparent paths of the moon and all the known planets were found to be spiral curves of more or less complexity, and described with very unequal velocities in their different parts. These bodies were observed, however, to have this in common, that the general direction of their motions is the same with that of the sun—viz. from west to east, contrary to that in which both they and the stars appear to be carried by the diurnal motion of the heavens, and moreover, that they cross and recross the ecliptic at regular and equal intervals of time, never deviating from the ecliptic on either side more than 8° or 9°. It is this zone of about 17° broad, having the ecliptic running along its middle, which was named the zodiac. Before the discovery of the asteroids, the zodiac restricted to the above limits formed the zone of the moving bodies of the heavens. But the orbits of many of the asteroids have a very considerable inclination to the ecliptic,—Pallas nearly 35°,—so that the significance of the zone of the zodiac is now, except in the most general sense, all but obsolete. The term zodiac is derived from the constellations of this zone being anciently figured as "animals." Its circuit was divided into twelve equal parts, the "sign" or symbol of each being taken from the constellation with which it then coincided. They are as follows:—

NORTHERN SIGNS.

♈ *Aries*, the Ram.
♉ *Taurus*, the Bull.
♊ *Gemini*, the Twins.
♋ *Cancer*, the Crab.
♌ *Leo*, the Lion.
♍ *Virgo*, the Virgin.

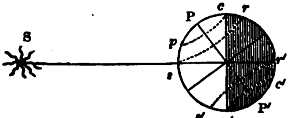
SOUTHERN SIGNS.

♎ *Libra*, the Balance.
♏ *Scorpio*, the Scorpion.
♐ *Sagittarius*, the Archer.
♑ *Capricornus*, the Goat.
♒ *Aquarius*, the Water-bearer.
♓ *Pisces*, the Fishes.

These constellations, however, do not cover the same parts of the ecliptic they formerly did, in consequence of the retrograde motion of the first point of Aries, or vernal equinoctial point, along the ecliptic, from which its divisions are reckoned. Hence the necessity of distinguishing between the *signs* of the ecliptic or zodiac and the *constellations* of the zodiac, the former being purely technical subdivisions of the ecliptic of 30° each commencing from the first point of Aries.—See Chart illustrating **Lunar-Distance Bodies.**

Zone (Gk. ζώνη, "a belt").—A zone of a sphere is the portion of its surface included between two parallel circles.

Zones of the Earth.—In consequence of the obliquity of the ecliptic, the surface of the earth is naturally divided into five zones or belts by the parallels of latitude called the Tropic of Cancer *sr* (about 23° 28′ N.) the Tropic of Capricorn *s′r′* (about 23° 28′ S.), the Arctic Circle *pc* (about 66° 32′ N.) and the Antarctic Circle *p′c′* (about 66° 32′ S.) When the sun is in either solstice, he will be in the zenith of some place situated in one of the tropics. Thus are these parallels defined, and they are, there-



fore, the parallels of latitude of about 23° 28′ N. and S.; they bound a zone of about 46° 56′ in breadth. Twice every year the sun is at noon close to, if not actually in the zenith of every place in this zone; it is consequently that of the greatest heat, and is hence called the *Torrid Zone*. Again, when the sun is in either solstice it enlightens the pole on that side of the equator, and shines beyond it through an arc P*c*, equal to the obliquity of the ecliptic (about 23° 28′); at the same time the opposite pole and the like extent of surface are enveloped in darkness. Within these zones (P*pc*, P′*p′c′*) during one portion of the year (longer or shorter according to the distance from the pole) the sun does not dip below the horizon, and during another portion of equal duration never rises above it in his diurnal revolution. As the sun's rays strike the earth's surface very obliquely in the polar zones, their temperature is very low, and they are hence called the *Frigid Zones*, *North* and *South*. Between the torrid zone and the frigid zones are two other zones, over no part of which the sun is ever vertical, but where he is seen to rise and set every day throughout the year; the temperature of these two belts is consequently intermediate between that of the torrid and frigid zones, and from this circumstance they are named the *Temperate Zones*, *North* and *South* (*rp*, *r′p′*). We must bear in mind, however, that owing to the different distribution of land and sea in the two hemispheres, zones of *climate* are not co-terminal with zones of *latitude*, and the above nomenclature is only to be accepted in a general sense.—See the figure under **Seasons**.

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